

DIESEL
PALMAR

GENERATOR SETS

SELECTION and INSTALLATION

CATERPILLAR ENGINE DIVISION

FOREWORD

Proper selection and installation of generator sets are vital to dependable performance and long, trouble-free life. But, in many cases, more attention is given to other aspects of power generation.

The specific intent of this guide, therefore, is to help the engineer in two ways:

- Make a knowledgeable choice of power equipment.
- Make an installation that results in reliable performance.

To further ensure a proper installation, Caterpillar has developed a supporting capability unmatched in the industry. From the conception of power needs, through the varied disciplines required for installation, to service and maintenance demanded years after completion, Caterpillar will continue its commitment to the success of the installation.

In the 40-odd years of developing power generation equipment, a practical but broad line of equipment has evolved. This provides cost-effective selection and ease of installation.

As a single source for engine, generator, and controls, the testing and quality control for a matched package is further assured.

The development of installation knowledge has paralleled that of the equipment. While this Selection and Installation Guide summarizes many aspects of installation, the Caterpillar Dealer stands ready to offer complete and detailed assistance.

SELECTION AND INSTALLATION FOR GENERATOR SETS CONTENTS

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SYSTEM DESIGN

The need for emergency or continuous electrical power is increasing rapidly. Commercial or public structures are many times totally dependent on an electrical energy source. Personnel safety, environmental considerations, and production schedules can be adversely affected by a lack of power integrity.

While an emergency or standby electrical source will usually conform to the normal utility supply, these restrictions are not imposed with an on-site power plant. This power system can be tailored to the exact requirements of the installation. Frequency, voltage, power levels, and distribution can be designed to maximize the system's operating safety, reliability, and efficiency.

The reasons for and the design of the equipment, which will satisfy the exact demands of the installation, should be defined in the preliminary planning of building design. The power network extends throughout an installation, and early consideration of its impact will avoid costly and time consuming design changes.

It is recommended that the table of contents of this guide be used as a checklist of those subjects which affect an on-site power plant. By referring to this index during the preliminary planning of each project, the effort and expense of after-installed changes can be avoided.

Engine Sizing

The initial consideration of a proposed on-site power system is the amount of power required in terms of kilowatts (kW). This is a summation of all loads connected to the generator. Rarely will all of the devices con-

nected to the generator operate simultaneously, so total connected load may not be the best guide in sizing a generator set. In the case of hospitals, however, the National Electric Code (NEC) requires sizing to the total connected emergency load. In most other applications, if the total connected load is used to size the generator set, the system cost may be unnecessarily high.

Where the generator set is to supply standby power, separate circuits are usually provided for critical or emergency loads. These loads must be totally satisfied when normal power fails, so the generator set must be sized to the total connected load of the emergency circuit.

The ratio of the actual load to the connected load is known as demand factor. (Not to be confused with load factor which is average load divided by peak load.) This ratio will change with time of day, season, and other factors. The size of the connected load can be determined by adding up the nameplate ratings of all connected loads. Motor horsepower ratings must be converted to kW values by means of Equation 4 in Figure 17 on Page 13, and the motor efficiency figures found in Figure 21, Page 15. For devices having unity power factors, such as lights or resistive heaters, kW and kV•A ratings will be identical.

The duration of the load must also be established if the plant is to achieve maximum efficiency. Chronological and duration curves best serve this purpose. The chronological daily load curve shows the total load at every moment of the day Figure 1A. This curve establishes peak demand on a particular day and aids in the selection of size and number of engines. It is also useful in programming units on and off the line for best operating economy.

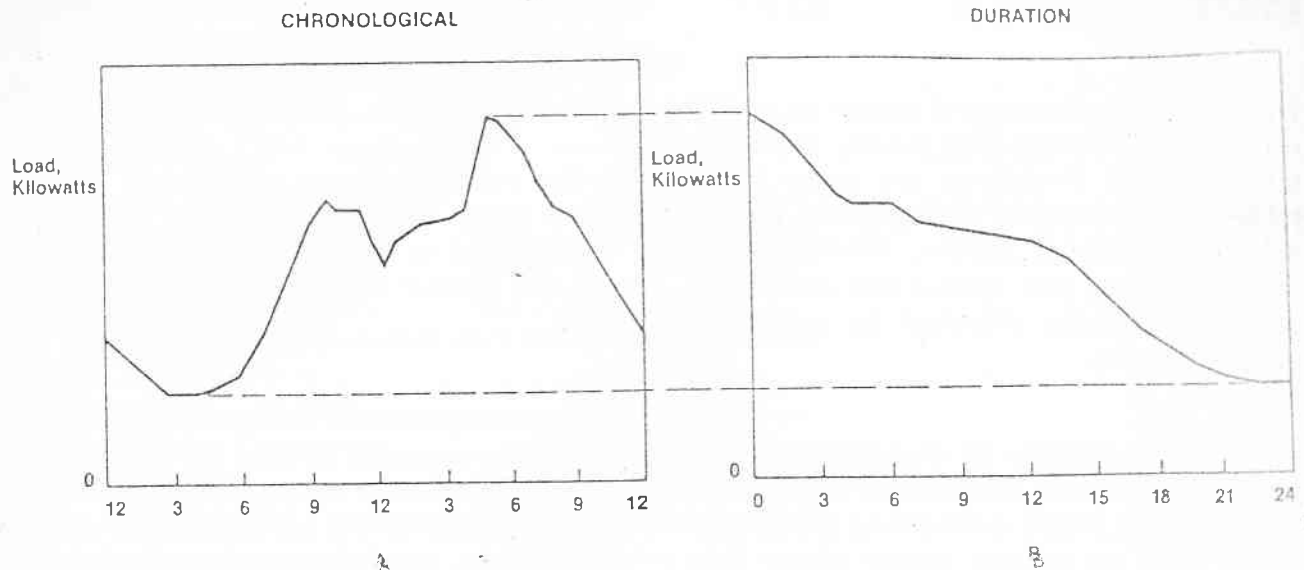


Figure 1

The duration curve is a rearrangement of the chronological curve and summarizes the daily load. Such curves can be developed for a week, month, or year and ease the task of plant design.

Motor Loads

In most cases, a motor may draw more than its rated kW during starting or run up to

rated speed. Motors connected directly to high inertia centrifugal devices or loaded reciprocating compressors may cause severe frequency excursions and lengthy motor run up. A comparison of starting currents from a loaded and unloaded motor shows the extended time the motor is subjected to high current.

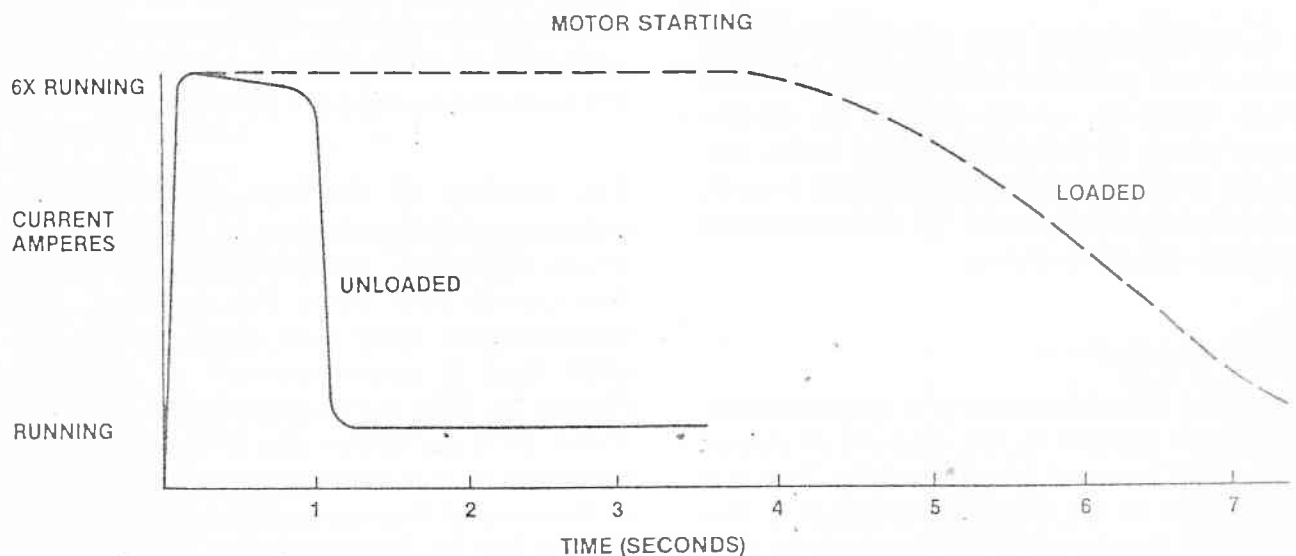


Figure 2

Motors generally exhibit a low power factor (pf) of 0.3 to 0.4 when starting. The load on the engine can be calculated by use of the equation:

$$kW = \text{Starting } kV \cdot A \times pf$$

On a motor started loaded, an analysis of its effect on both the engine and generator should be made, particularly if the motor is relatively large, has a high inertia load, and increases its load as the motor accelerates (example, large centrifugal fans, pumps).

Motor Torque

The motor load of a system must be established to determine if the generator and the engine have, respectively, adequate $kV \cdot A$ and kW. Motor load can be considered as the torque required by the load. This torque, in lb-ft ($N \cdot m$), is usually related to the speed at which it is required. Therefore, motor load in horsepower equals:

$$hp = \frac{lb \cdot ft \times rpm}{5,250} \text{ or } \frac{(N \cdot m : rpm)}{7,350}$$

To describe the motor load accurately, consideration must be given to the torque requirements under the following conditions: (These torques are usually expressed as a percent of running torque.)

Starting (Breakaway) Torque

This is the maximum torque required to start the load and is a function of the voltage available at the motor terminals.

Accelerating Torque

This is the net difference at any speed between the required torque and the available torque.

The minimum accelerating torque capability must always exceed the maximum accelerating torque demanded by its connected load. The time necessary to achieve full rated speed must also be considered.

Too little accelerating torque could result in prolonged accelerating time, overheating the motor. This time can be calculated by:

$$t^* = \frac{J(n_2 - n_1)}{9.55 T_a}$$

Where: t = Accelerating Time, Seconds

n_2 = Final Speed, rpm

n_1 = Initial Speed, rpm

T_a = Available Motor Accelerating Torque, (At Resultant Voltage Dip) lb-in ($N \cdot m$)

J = Inertia Load, lb-in-s² ($N \cdot m \cdot s^2$)

*The time, "t," in seconds should not exceed 15 seconds without consulting the motor manufacturer.

Synchronous Torque

The steady-state torque developed by a synchronous motor at rated speed.

Peak Torque

This is the maximum torque that a machine requires from its driving motor.

Regenerative Power

In some motor applications, such as motors used for hoisting, the load depends on the motor for braking. The motor then acts as a generator and feeds power back to the generator set. If no other loads are connected to absorb this regenerative energy, only the frictional horsepower of the engine can be relied upon for braking. Exceeding this frictional horsepower can cause the generator set to overspeed.

The regenerative potential for the most common application, elevators, can be estimated by:

$$kW = \frac{\text{Hoist Motor Horsepower}}{0.9 \times 1.6 \times 0.5 \times 0.746}$$

Where: 0.9 is Motor Efficiency
 1.6 is Full Load Acceleration "Up" Factor
 0.5 is Full Load Acceleration "Down" Factor
 0.746 is Horsepower to kW Conversion

When the combination of connected load and engine frictional horsepower are not sufficient to restrain the regenerative energy, a load bank may be added to the

system. It can be activated by means of directional power relays.

GENERATOR SIZING

As with the engine selection, the generator must be capable of meeting the demands of the load. While the engine was concerned with power (kW) and frequency control, generator capability is noted in kV•A and voltage control. Engine and generator performances are related by the following formula:

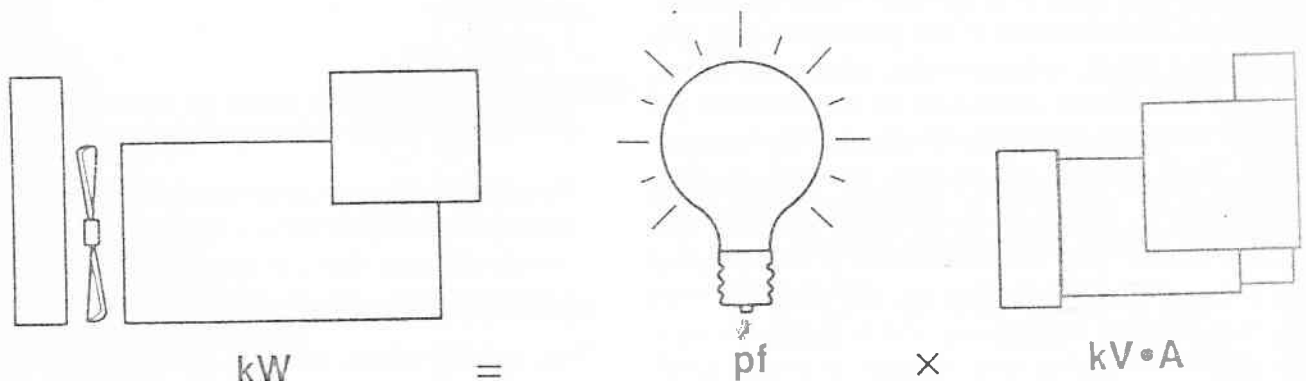


Figure 3

$$kW = pf \times kV \cdot A$$

Power Factor

Power factor (pf) is determined by the connected load. The power factor carried on the nameplate of the generator has only an indirect relationship to generator design. But it does aid in relating the kV•A rating of the generator to the kW rating of the engine.

In most magnetic circuits, the current will lag behind the voltage. Figure 4 represents

a circuit in which current changes lag corresponding voltage changes 60 degrees (1/6 cycle). In that part of the wave where both are positive, or both negative, the resulting power is positive. This is represented by the shaded area above the zero line.

When either the current or voltage is negative, while the other is positive, the resulting power is negative. This is represented by the shaded area below the zero line.

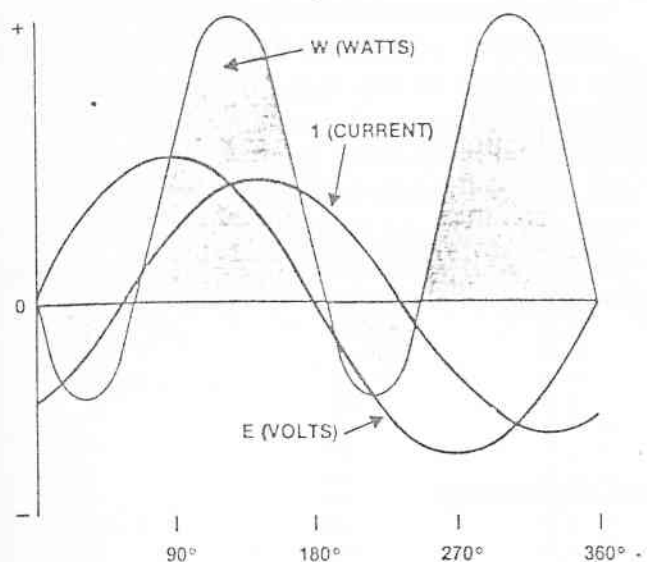


Figure 4

NET POWER is the positive area minus the negative area.

APPARENT POWER is the sum of the two areas.

POWER FACTOR is the NET POWER divided by the APPARENT POWER.

Mathematically, power factor is equal to the cosine of the angle by which the current lags (or in rare cases leads) the voltage. In Figure 4 the angle of lag is 60 degrees. The cosine of this angle and thus the corresponding power factor, for that amount of lag is 0.50 corresponding to 0.5 (or 50%) lagging power factor.

A 0.8 pf is suggested by NEMA for standard generator design. In most commercial applications where motor loads are combined with heating and lighting loads, a power factor of 0.8-0.9 may be assumed.

POWER FACTOR OF TYPICAL AC LOADS

UNITY (OR NEAR UNITY) POWER FACTOR		LAGGING POWER FACTOR		LEADING POWER FACTOR
Load	Approximate Power Factor	Load	Approximate Power Factor	Load
Incandescent Lamps (Power factor of lamp circuits operating off step-down transformers will be somewhat below unity.)	1.0	Induction Motors (Rated load and speed.)		Synchronous Motors (Are designed in standard ratings at unity, 0.9 and 0.8 leading power factor.)
Fluorescent Lamps (With built-in capacitor)	0.95 to 0.97	Split Phase Below 1 hp	0.55 to 0.75	Synchronous Condensers (Nearly zero leading power factor. Output practically all leading reactive kV•A.)
Resistor Heating Apparatus	1.0	Split Phase, 1 hp to 10 hp	0.75 to 0.85	
Synchronous Motors (Operate at leading power factor at part loads; also built for leading power factor operation.)	1.0	Polyphase, Squirrel Cage		Capacitors (Zero leading power factor. Output practically all leading reactive kV•A.)
Rotary Converters	1.0	High Speed, 1 hp to 10 hp	0.75 to 0.90	
		High Speed, 10 hp and Larger	0.85 to 0.92	
		Low Speed	0.70 to 0.85	
		Wound Rotor	0.80 to 0.90	
		Groups of Induction Motors	0.50 to 0.90	
		Welders		
		Motor Generator-Type	0.50 to 0.60	
		Transformer-Type	0.50 to 0.70	
		Arc Furnaces	0.80 to 0.90	
		Induction Furnaces	0.60 to 0.70	

Figure 5

Motor Starting

Motors, either loaded or unloaded, will draw several times their rated full-load current. This is referred to as locked rotor current or starting kV•A (skV•A). Refer to Figure 7 for the locked rotor current of three-phase induction motors. skV•A can be calculated from locked rotor current by the following formula:

$$\text{skV}\cdot\text{A} = \frac{V \times A \times 1.732}{1,000}$$

As a result of the in-rush current to the motor, the generator output voltage will rapidly drop. In most cases a 30% voltage dip is acceptable, but the exact nature of this dip must be identified by an oscilloscope. Meters or mechanical recorders are too slow for this measurement.

EFFECT OF MOTOR STARTING

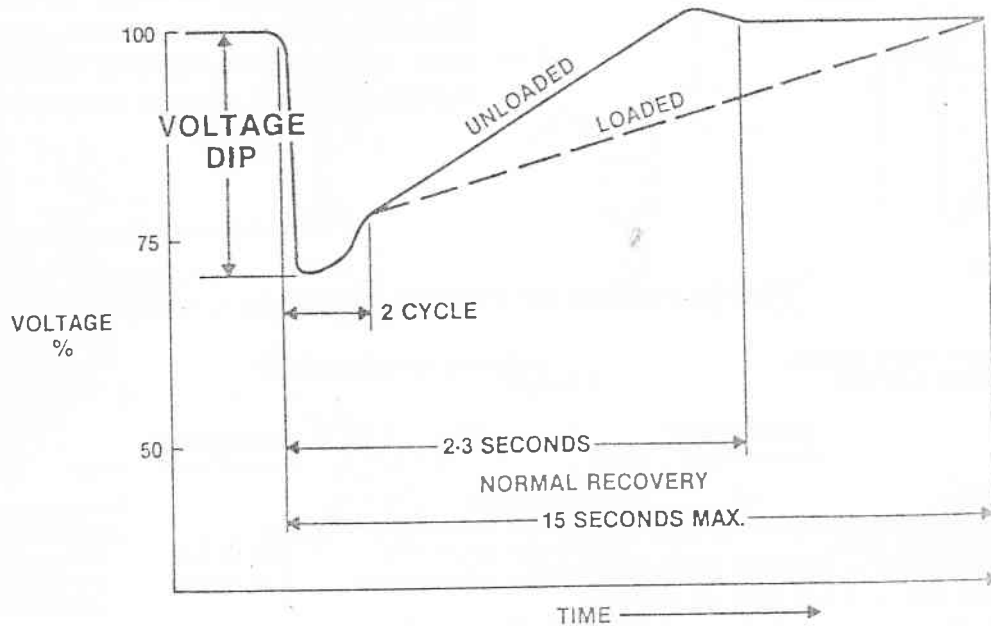


Figure 6

Single-speed, three-phase, constant-speed induction motors, when measured with rated source voltage and frequency impressed

and with rotor locked, shall not exceed the following:

LOCKED ROTOR CURRENT — NEMA MG 1

60 Hz — 230 Volts

Horsepower	Locked Rotor Current, Amperes*	Design Letters
1/2	20	B, D
3/4	25	B, D
1	30	B, D
1-1/2	40	B, D
2	50	B, D
3	64	B, C, D
5	92	B, C, D
7-1/2	127	B, C, D
10	162	B, C, D
15	232	B, C, D
20	290	B, C, D
25	365	B, C, D
30	435	B, C, D
40	580	B, C, D
50	725	B, C, D
60	870	B, C, D
75	1085	B, C, D
100	1450	B, C, D
125	1815	B, C, D
150	2170	B, C, D
200	2900	B, C
250	3650	B
300	4400	B
350	5100	B
400	5800	B
450	6500	B
500	7250	B

50 Hz — 380 Volts

Horsepower	Locked Rotor Current, Amperes*	Design Letters
1 or less	20	B, D
1-1/2	27	B, D
2	34	B, D
3	43	B, C, D
5	61	B, C, D
7-1/2	84	B, C, D
10	107	B, C, D
15	154	B, C, D
20	194	B, C, D
25	243	B, C, D
30	289	B, C, D
40	387	B, C, D
50	482	B, C, D
60	578	B, C, D
75	722	B, C, D
100	965	B, C, D
125	1207	B, C, D
150	1441	B, C, D
200	1927	B, C

*The locked rotor current of motors designed for voltages other than 380 volts shall be inversely proportional to the voltages.

*Locked rotor current of motors designed for voltages other than 230 volts shall be inversely proportional to the voltages.

Figure 7

Motor Starting Techniques

If motor starting is a problem, these suggestions can be considered:

1. **Change starting sequence.** Start largest motors first. More kV•A is available for starting although it does not provide better voltage recovery time.
2. **Use reduced voltage starters.** This reduces the kV•A required to start a given motor. If starting under load, remember this method of starting also reduces starting torque.
3. **Specify an oversized generator.**
4. **Use wound rotor motors.** They require much lower starting current, but are expensive.
5. **Provide clutches** so motors may be started before loads are applied to them. While the starting kV•A demand of the motor is not reduced, the time interval of high kV•A demand is reduced.
6. **Improve the system power factor.** This reduces the generator set requirement to produce reactive kV•A; making more kV•A available for starting.
7. **Use a motor generator set.** A motor drives the generator which, in turn, supplies power to the motor to be started as is done, for example, in elevator service. The motor generator set runs continuously and the current surge caused by the starting of the equipment motor is isolated from the remainder of the load.

Full-Voltage Starting

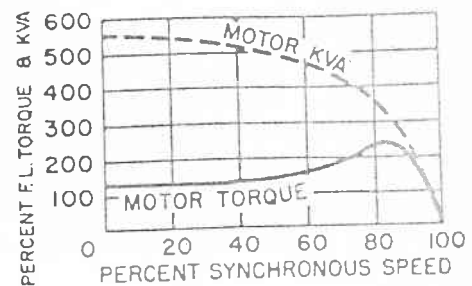
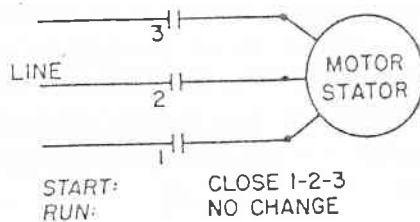


Figure 8

Full voltage, across-the-line starting is simple, low cost, and preferred whenever system capacity and performance permits. In this type of starting, full-line voltage is supplied to the motor the instant the motor switch is actuated. Maximum starting torque is available. The generator set must have sufficient motor starting $kV \cdot A$ capacity to prevent voltage drop from exceeding acceptable limits. If the actual value of motor starting current cannot be determined, an approximate value of 600% of the full load rated current is sometimes applied.

Reduced Voltage Starting

There are several methods of operating motors at reduced voltages during the start-

ing period. Reduced voltage starting will decrease the motor's starting torque. This can seriously detract from the motor's ability to start and achieve rated speed when burdened by a load. The time required to reach full operating speed will also be increased.

Note that the reduction in motor torque is usually very close to the square of the voltage reduction. For example, an 80% reduced voltage starter will allow the motor, upon starting, to initially produce only 64% (80% voltage²) of available full speed torque. See Figure 15.

Autotransformer — Open

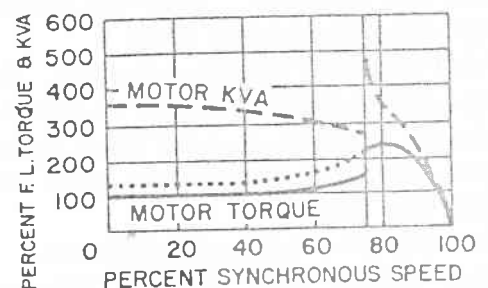
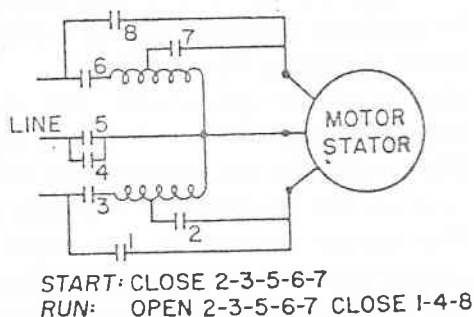


Figure 9

Also called autocompensators, autotransformer starters are commonly used because they provide higher starting torque per ampere than any other type of reduced voltage starter. They are available in ratings up to several hundred horsepower for both high- and low-voltage motors. The autotransformer primary is connected to the supply

line, and the motor to the low-voltage taps until the motor reaches a predetermined speed. The autotransformer is then disconnected and the motor is connected directly to the line. The simplest arrangement is open circuit transfer from reduced to full voltage. This can cause severe electrical or mechanical disturbances.

Autotransformer — Closed

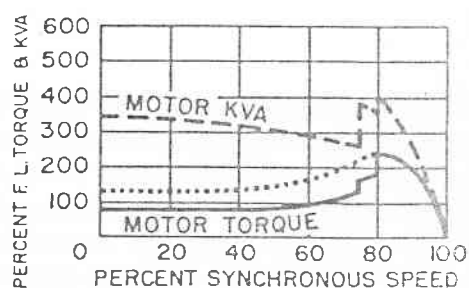
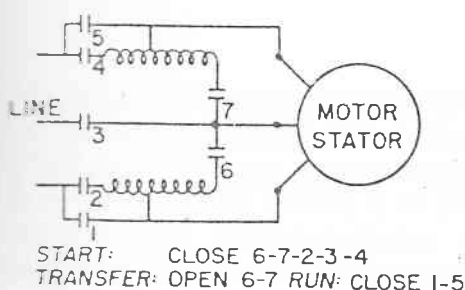


Figure 10

An alternative, and increasingly popular method, is closed transition (Korndorfer). This technique minimizes shock and provides continuous positive torque during transfer to full voltage.

Autotransformer starters are magnetically controlled. Normally, there are three taps on the transformer secondary. The first tap is set for 50%, the second for 65%, and the third for 80% of full-line voltage. The cur-

rent drawn from the line will vary as the square of the voltage at the motor terminals. Thus, when the motor is connected to the third (80%) tap, the line current will be $(80\%)^2$, or 64% of the line current that would be drawn at full voltage. The starter will require approximately 25 kV•A per 100 motor horsepower as magnetizing current. This magnetizing current must be added to the starting kV•A segment of the motor being started.

Reactor

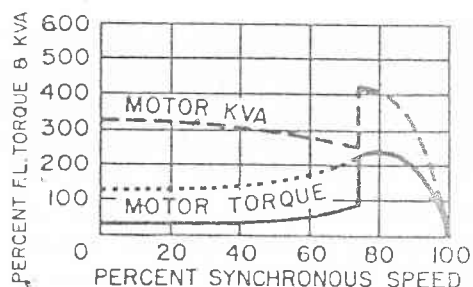
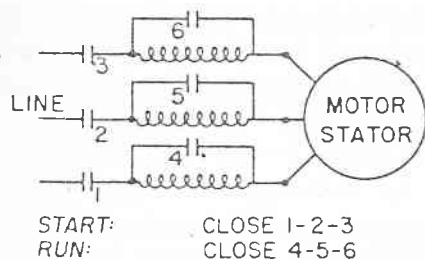


Figure 11

Resistor

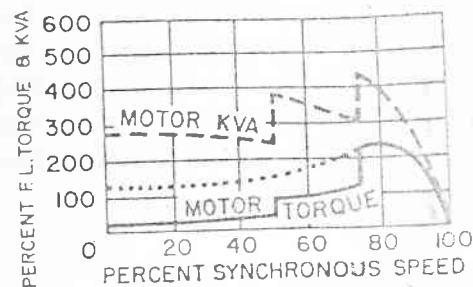
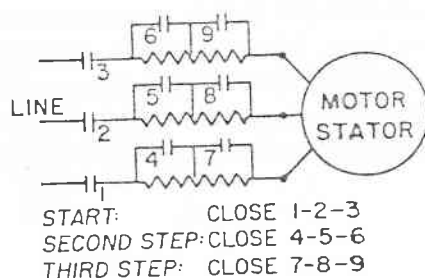


Figure 12

Reactor and resistor starters accomplish voltage reduction across the stator windings by inserting resistance or reactance in each leg of the stator circuit during starting and shorting it out when the motor reaches operating speed. This method has the advantage of providing smooth acceleration as the starting circuit is removed, without

momentarily disconnecting the motor from the line. However, line current is equal to the motor coil current. This technique results in a poorer torque-to-kV•A ratio than the autotransformer compensator, but it does provide closed-transition starting and is normally lower in price.

Part Winding

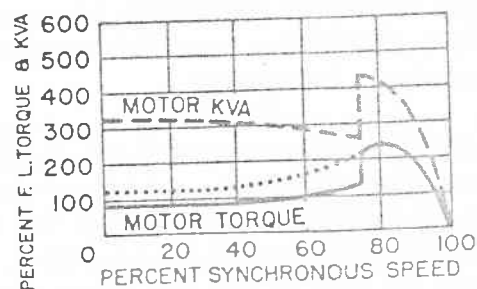
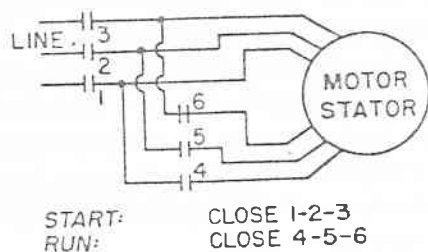


Figure 13

This method requires a special motor having the stator wound with two or more parallel circuits which are successively connected to the line as the motor speed increases.

Closed-transition starting and a good ratio of torque to kV•A may be realized, but the technique is not suitable for small or high-speed motors.

Wye Delta (Star Delta)

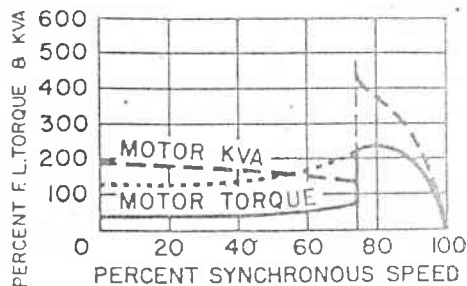
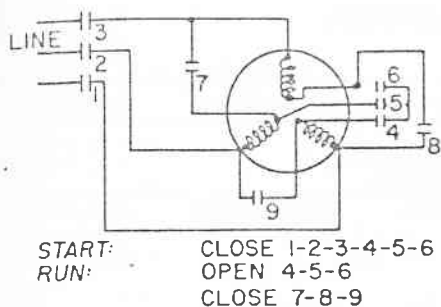


Figure 14

In this method, the motor starts as a wye-connected motor and runs delta connected. It has a simple motor connection. The trans-

fer is open transition, and torque is limited to 33% of full-voltage torque levels.

REDUCED VOLTAGE STARTERS

Type of Starter	Motor Voltage % Line Voltage	Line Current % Full Voltage Starting Current	Starting Torque % of Full Voltage Starting Torque
Full Voltage Starter	100	100	100
Autotransformer			
80% Tap	80	68	64
65% Tap	65	46	42
50% Tap	50	30	25
Resistor Starter			
Single Step (Adjusted for motor voltage to be 80% of line voltage.)	80	80	64
Reactor			
50% Tap	50	50	25
45% Tap	45	45	20
37.5% Tap	37.5	37.5	14
Part Winding (Low speed motors only.)			
75% Winding	100	75	75
50% Winding	100	50	50
Star Delta	57	33	33

Figure 15

The typical motor starting curve in Figure 2 is affected by the design of the motor and generator and by the load on the motor. But, the great majority of the initial voltage dip is dependent only on the motor and generator windings. The addition of series boost to the regulator or use of a permanent magnet exciter will not decrease this dip.

The magnitude of the voltage dip which can be tolerated depends on the type of equipment on the line. Motor starting contactors will usually open if voltage drops below 65% of rated. A voltage dip of less than 30% is, therefore, commercially acceptable. Figure 16 summarizes typical equipment tolerances.

TYPICAL EQUIPMENT POWER TOLERANCES

Device	Voltage		Frequency	Harmonics and Noise	Remarks
	Variation	Duration of Interruption	Variation		
NEMA Induction Motors	± 10%	Varies With Load 30 Cycle Reclosure Usually Acceptable	± 5%	Increases Heat	Sum of Voltage and Frequency Not to Exceed ± 10%
NEMA AC Control Relays	± 10% Continuously Pickup On — 15% Hold In — 25% (Approximate)	Drops Out In One Cycle or Less	± 5%	Insensitive	
Solenoids-Valves, Brakes, Clutches	± 30% to 40%	1/2 Cycle			
Starter Coils, Motor Contactors					
AC Dropout	- 30% to - 40%	2 Cycles			
AC Burnout	- 15% to 10%	Continuous			
DC Dropout	- 30% to - 40%	5 to 10 Cycles			
Fluorescent Lights	- 10%				Erratic Start
Incandescent Lights	- 25% to + 15%				Short Life
Mercury Vapor Lights	- 50%	2 Cycles			Extinguished
Communications Radio, TV, Telephone	± 5%			Variable Sensitive to Spike	
Computers	± 10% - 8%	1 Cycle	+ 1/2 Hz	5%	
Electronic Tubes	± 5%			Variable	
Inverters	+ 5% at Full Load		± 2 Hz	2% Sensitive to Spikes	May Require Isolating Trans- former, Filters
Thyristor (SCR)	+ 10% at No Load, - 10% Transient			Sensitive	
Rectifiers, Solid- State Diode	± 10%			Sensitive	

NOTE: Final Determination of Power Requirements Must Result From Equipment Supplier's Specific Recommendations

Figure 16

ELECTRICAL FORMULAE

To Obtain	Alternating Current		Direct Current	
	Single-Phase	Three-Phase		
kW atts	$\frac{V \times I \times pf}{1,000}$	$\frac{1.732 \times V \times I \times pf}{1,000}$	$\frac{V \times I}{1,000}$	(Eq. 1)
kV•A	$\frac{V \times I}{1,000}$	$\frac{1.732 \times V \times I}{1,000}$		(Eq. 2)
Horsepower Required To Drive Known kW Generator	$\frac{kW}{.746 \times \text{Eff. (Gen.)}}$	$\frac{kW}{.746 \times \text{Eff. (Gen.)}}$	$\frac{kW}{.746 \times \text{Eff. (Gen.)}}$	(Eq. 3)
kW Input To a Motor of Known hp	$\frac{hp \times .746}{\text{Eff. (Motor)}}$	$\frac{hp \times .746}{\text{Eff. (Motor)}}$	$\frac{hp \times .746}{\text{Eff. (Motor)}}$	(Eq. 4)
Full Load Amperes When Motor Horsepower is Known	$\frac{hp \times 746}{V \times pf \times \text{Eff.}}$	$\frac{hp \times 746}{1.732 \times V \times \text{Eff.} \times pf}$	$\frac{hp \times 746}{V \times \text{Eff.}}$	(Eq. 5)
Amperes When kW is Known	$\frac{kW \times 1,000}{V \times pf}$	$\frac{kW \times 1,000}{1.732 \times V \times pf}$	$\frac{kW \times 1,000}{V}$	(Eq. 6)
Amperes When kV•A is Known	$\frac{kV \cdot A \times 1,000}{V}$	$\frac{kV \cdot A \times 1,000}{1.732 \times V}$		(Eq. 7)
Frequency (cps)	$\frac{\text{Poles} \times \text{rpm}}{120}$	$\frac{\text{Poles} \times \text{rpm}}{120}$		(Eq. 8)
Reactive kV•A (kV•AR)	$\frac{V \times I \times \sqrt{1 - (pf)^2}}{1,000}$	$\frac{1.732 \times V \times I \times \sqrt{1 - (pf)^2}}{1,000}$		(Eq. 9)
% Voltage Regulation	$\frac{100 (V_{NL} - V_{FL})}{V_{FL}}$	$\frac{100 (V_{NL} - V_{FL})}{V_{FL}}$	$\frac{100 (V_{NL} - V_{FL})}{V_{FL}}$	(Eq. 10)

Where: V = Line-To-Line Volts
I = Line Current Amperes
pf = Power Factor

Figure 17

**THREE-PHASE AC MOTORS — 80% POWER FACTOR
FULL-LOAD CURRENT IN AMPERES
INDUCTION-TYPE SQUIRREL CAGE AND WOUND ROTOR**

Horsepower	110 V	208 V	220 V	440 V	550 V
1/2	4	2.1	2	1	.8
3/4	5.6	3	2.8	1.4	1.1
1	7	3.7	3.5	1.8	1.4
1-1/2	10	5.3	5	2.5	2
2	13	6.9	6.5	3.3	2.6
3		9.5	9	4.5	4
5		16	15	7.5	6
7-1/2		23	22	11	9
10		29	27	14	11
15		43	40	20	16
20		55	52	26	21
25		68	64	32	26
30		83	78	39	31
40		110	104	52	41
50		133	125	63	50
60		159	150	75	60
75		198	185	93	74
100		262	246	123	98
125		330	310	155	124
150		380	360	180	144
200		510	480	240	192
250		697	657	328	262
300		837	790	394.5	315
350		976	922	461	368
400		1114	1051	526	421
450		1254	1192	592	473
500		1393	1317	657	526
600		1672	1578	789	632
700		1950	1842	921	737
800		2220	2103	1051	842
900		2504	2365	1194	947
1000		2789	2639	1316	1050

Figure 18

**SINGLE-PHASE AC MOTORS
FULL-LOAD CURRENT IN AMPERES**

Horsepower	kW	100 V	200 V	208 V	230 V	380 V	400 V	415 V
1/2	0.45	4	2.2	2.1	1.9	1.1	1.1	1.1
3/4	0.68	5.6	3.1	3	2.7	1.6	1.6	1.5
1	0.9	7	3.8	3.7	3.3	2	1.9	1.9
1-1/2	1.5	10	5.5	5.3	4.8	2.9	2.8	2.7
2	1.8	13	7.2	6.9	6.2	3.8	3.6	3.5
3	2.6		9.9	9.5	8.6	5.2	5	4.8
5	4.4		16.6	16	14.5	8.8	8.3	8
7-1/2	6.6		24	23	20.8	12.6	12	11.5
10	8.8		30	29	26	16	15	14.5

Figure 19

**DIRECT CURRENT MOTORS
FULL-LOAD CURRENT IN AMPERES**

Horsepower	115 V	230 V	550 V
1/4	3	1.5	
1/3	3.8	1.9	
1/2	5.4	2.7	
3/4	7.4	3.7	1.6
1	9.6	4.8	2
1 1/2	13.2	6.6	2.7
2	17	8.5	3.6
3	25	12.5	5.2
5	40	20	8.3
7-1/2	58	29	12
10	76	38	16
15	112	56	23
20	148	74	31
25	184	92	38
30	220	110	46
40	292	146	61
50	360	180	75
60	430	215	90
75	536	268	111
100		355	148
125		443	184
150		534	220
200		712	295

Figure 20

**APPROXIMATE EFFICIENCIES —
SQUIRREL CAGE INDUCTION MOTORS**

Horsepower	Full-Load kW Required	Full-Load Efficiency
1/2	0.6	68%
3/4	0.8	71
1	1	75
1-1/2	1.5	78
2	1.9	80
3	2.7	82
5	4.5	83
7-1/2	6.7	83
10	8.8	85
15	13	86
20	16.8	89
25	21	89
30	24.9	90
40	33.2	90
50	41.5	90
60	49.2	91
75	61.5	91
100	81.2	92
125	101.5	92
150	122	92
200	162.5	92
250	203	92
300	243	92
350	284	93
400	321	93
450	362	93
500	401	93
600	482	93

Figure 21

**MOTOR STARTING CHARACTERISTICS AS
DESIGNED BY BRITISH STANDARD 2613**

Design	Starting kV•A (Locked Rotor) Not to Exceed
A	Column 1 of Figure 23
B	Column 2 of Figure 23
C	Column 2 of Figure 23
D	Column 3 of Figure 23
E	Column 3 of Figure 23
F	Column 1 of Figure 23
G	Subject to Agreement

Figure 22

Starting (Locked Rotor) kV•A

Rated Output (kW)			Ratio • $\frac{\text{Starting (Locked Rotor) kV•A}}{\text{Rated Output kW}}$	
			Column 1	Column 2 Column 3
Over 1.0 up to 2.5				10.5
Over 2.5 up to 6.3				9.8
Over 6.3 up to 16				9.2
Over 16.0 up to 40			In Excess of Ratios Given in Column 2	8.7
Over 40 up to 100				8.2
Over 100 up to 250				7.8
Over 250 up to 650				7.6
Over 650 up to 1600				7.4
Over 1600 up to 4000				7.2
Over 400 up to 10000				7.0

*To obtain the ratio of starting (locked rotor) current to rated load current, multiply this ratio by per unit efficiency and power factor at rated load.

Figure 23

IDENTIFYING CODE LETTERS ON AC MOTORS

NEMA Code Letter	Starting kV•A Per Horsepower
A	0.00- 3.14
B	3.15- 3.54
C	3.55- 3.99
D	4.00- 4.49
E	4.50- 4.99
F	5.00- 5.59
G	5.60- 6.29
H	6.30- 7.09
J	7.10- 7.99
K	8.00- 8.99
L	9.00- 9.99
M	10.00-11.19
N	11.20-12.49
P	12.50-13.99
R	14.00-15.99
S	16.00-17.99
T	18.00-19.99
U	20.00-22.39
V	22.40-

Note: Code letters apply to motors up to 200 hp.

Figure 24

EQUIPMENT CONSIDERATIONS

Lighting

Incandescent lamps are rated by voltage and wattage requirements, and may be operated on either alternating or direct current. The current drawn by a lamp may be found by dividing the wattage rating by the specified input voltage,

A = W / V

since the power factor is unity. They draw high in-rush currents and are suitable in applications which require flashing or dimming, with operation over a wide voltage range. However, any voltage fluctuation will affect the brightness of the lamp, and extreme voltages will shorten filament life.

Fluorescent lamps are also rated by voltage and wattage. These lamps have a slightly lower power factor (0.95 to 0.97) due to their ballast transformer but, for sizing purposes, a unity power factor may be assumed. When either type light is operated from a step-down transformer, the power factor contribution of the transformer must also be considered.

The human eye is sensitive to slight lighting fluctuations. A decrease of 1/2 volt on a 110-volt incandescent bulb is noticeable to the eye. A dip of over one volt, if repeated, becomes objectionable. Figure 25 shows range of observable and objectionable voltage dips at various frequencies. This is based on direct illumination and medium-sized bulbs.

VOLTAGE LEVEL FLUCTUATION LIMITS

Voltage Variation	Permissible Frequency of Occurrence
± 1-1/2%	20 Times Per Second
± 2-1/2%-5%	2 Times Per Second
± 5%-10%	1 Time Per Hour

Figure 25

If indirect lighting is used and there are no incandescent bulbs below 100 watts, some leeway may be used in interpreting the values. This is also true if all lighting is fluorescent rather than incandescent.

Reciprocating compressors can seriously affect lighting quality. The torque pulsations may cause variation in motor current which results in sufficient voltage fluctuation to cause light flicker. Unfortunately, this is usually at a frequency to which the eye is extremely sensitive.

A commonly accepted figure of current variation for a motor driving a reciprocating compressor is 66% of full-rated motor current. This generally limits the horsepower rating of a compressor motor to about 6% of the generator kV•A rating if objectionable light flicker is to be avoided. For example, a 30 hp motor may be used on a system having not less than 500 kV•A of generator capacity in operation.

If a large compressor motor must be used, the allowable percentage of current variation must be decreased in proportion. If the motor horsepower rating is 10% of the generating capacity of the allowable current, variation can only be 6/10 × 66 = 39.6%.

General requirements for typical installations are listed.

TYPICAL VOLTAGE DIP LIMITATIONS

Application	Condition	Permissible Voltage Dip
Hospital, hotel, motel, apartments, libraries, schools, and stores.	Lighting load, large. Power load, large. Flickering highly objectionable.	2% Infrequent
Movie theaters (sound tone requires constant frequency. Neon flashers erratic.)	Lighting load, large. Flickering objectionable.	3% Infrequent
Bars and resorts.	Power load, large. Some flicker acceptable.	5%-10% Infrequent
Shops, factories, mills, laundries.	Power load, large. Some flicker acceptable.	3%-5% Frequent
Mines, oil field quarries, asphalt plants.	Power load, large. Flicker acceptable.	25%-30% Frequent

Figure 26

Motors

AC electric motors represent an inductive load and have a lagging power factor between 0.5 and 0.95, depending on size, type, and loading. An exception is synchronous motors which have unity or even leading power factors, depending on excitation.

Motors draw large starting currents, between two to eight times their normal running current. The mechanical load on the motor does not vary the maximum starting current, but it does determine the length of time required for the motor to achieve rated speed and for the current to drop back to the normal running value. If the motor is excessively loaded, it may not start at all or may run at reduced speed. Both the starting and the running current must be considered when analyzing the total kV•A requirement.

A number of different types of motors are in common use. Each is selected for its particular characteristics, and each represents a somewhat different type of starting and running load.

Induction

The most common motor is the induction type. These motors are applied in both single-phase or three-phase duty. Three-phase motors are generally specified when the load exceeds 1 hp due to their lower cost, simplicity, and higher efficiency.

Motors which are rated 1 hp or less are normally single-phase or various designs. Four general types are:

Type	Horsepower	kV•A Horsepower*
Split Phase	To 1/3	12.5
Repulsion-Induction	To 2	6
Capacitor Start	To 2	7.5
Capacitor Start and Run	To 2	7.5

*These values apply when operating on single-phase generators or when balanced on three-phase generators. When operating on one phase of a three-phase generator, unbalanced loading will occur and the noted kV•A values must be doubled. Unbalanced loading of three-phase generator must be avoided when possible. When practical, single-phase motors should be placed on the regulated phase or phases of the generator.

Figure 27

SINGLE-PHASE AC MOTORS FULL-LOAD CURRENTS IN AMPERES

Horsepower	115 V	208 V	230 V	440 V
1/4	5.8	3.2	2.9	
1/3	7.2	4.0	3.6	
1/2	9.8	5.4	4.9	
3/4	13.8	7.6	6.9	
1	16	8.8	8	
1-1/2	20	11	10	
2	24	13.2	12	
3	34	19	17	
5	56	31	28	
7-1/2	80	44	40	21
10	100	55	50	26

Figure 28

Squirrel Cage

Most three-phase motors are of the squirrel cage-type. The U.S. National Electric Manufacturers' Association (NEMA) uses two methods of classification: by design and by code. The motor nameplate normally carries both these designations. There is no direct

relationship between NEMA design and code designations.

The most common NEMA designs are:

Types	Typical Uses
B-Normal starting torque, low starting current.	Fans, blowers, compressors (started unloaded), centrifugal pumps, generators.
C-High starting torque, low starting current, moderate full load slip.	Reciprocating compressors (starting loaded), conveyors, elevators (high breakaway), crushers (starting loaded), positive displacement pumps.
D-High starting torque, low starting current, high slip.	Chippers and punch presses.

Wound Rotor (Slip Ring)

Wound rotor motors use slip rings, or collector rings, to connect the rotor windings to an external switch-controlled resistor for regulation of starting current. Usually, these motors are started at almost unity power factor, depending upon control, and their starting current can be limited to about 130% of rated operating current. They are used where equipment must be started under heavy load and for variable speed operation. Because they have no code letter, exact operating performance must be found on the motor nameplate or by consulting the manufacturer.

Synchronous

Synchronous motors are designed to maintain a constant speed of rotation, synchronized with the power line frequency. They are seldom found in sizes under 40 hp. Synchronous motor power factor is a function of load and excitation. Some are designed to produce leading power factors at full load as an aid to improving the overall system power factor. Synchronous motors are started as induction motors, so sufficient system capacity must be available to ensure starting current demands are met.

The characteristics of a specific synchronous motor must be obtained from the motor manufacturer.

DC Motors

Motors designed for operation from direct current are used where their speed control or heavy load starting capability is required or where other elements of a system require the use of a DC power source. Full-load efficiencies will vary from 86% to 92%.

Transformer

While energizing, transformers have inductive characteristics similar to a motor. Initial current is usually eight to ten times that of rated. To control voltage fluctuation, the kV•A capability of a proposed generator must include starting of this low power factor load.

Silicone-Controlled Rectifier — (SCR) Motor Controls

SCR control devices lend themselves to infinite speed control of motors. When used with a limited power source, such as an engine-driven generator set, the switching of SCR controls can cause severe voltage wave form distortion. This may adversely affect the performance of the entire system. When planning a system with SCR controls, the control manufacturer must be informed it will operate from a limited power source. He can then design the system to minimize this problem.

Computers

When computers are a portion of the load, the required power quality should be specified by the computer's manufacturer prior to power system design to ensure system compatibility. As a general rule, heavy block loads and large motor skV•A are avoided on a computer power supply.

Communications Equipment

Communications equipment includes a broad range of electronic devices used for the transmission of information. The most common types are radio and television broadcasting equipment, including both studio units and transmitters, telephone equipment, and microwave relay transmitters. In general, all of these devices pass their power supply through transformers. Therefore, the power factor will be slightly less than unity. Most equipment will tolerate frequency variations of $\pm 5\%$, except where synchronous timing devices are used. Voltage variations of $\pm 10\%$ are usually acceptable since electronic circuits, which are sensitive to voltage variations, are usually designed with internal voltage regulation devices.

Power for complex telephone systems is frequently supplied from the building power mains. Since telephone operation can be essential to public safety, some units are also supported from the emergency power source. The voltage and frequency stability requirements for telephone equipment are generally not severe, but the use of solid-state battery chargers can disturb system monitoring services. SCR devices also affect the voltage wave form of the power source. In the case of a limited power source, i.e., emergency generator, the wave form is seriously altered. If other equipment, sensitive to wave form (timing devices, monitors, amplifiers), is operated from the same AC bus, its performance can be erratic. Total isolation of the sensitive equipment from the limited source AC bus may be necessary.

GENERATORS

Most generators purchased in the U.S. follow the design criteria as described by the National Electric Manufacturers' Association (NEMA). As part of this criteria, the temperature limitations of various wire insulations are described. The following major NEMA considerations are met by all Caterpillar Generators.

NEMA Considerations

MG 1-22.40

Generator Windings	Temperature Rise, °C*			
	A	B	F	H
Continuous Duty	60	80	105	125
Standby Duty	85	105	130	150

*Measured by resistance. Deduct 10°C if measurement by thermometer. Actual measurement by thermometer considered inaccurate. Air entering the generator, 40°C maximum.

Figure 29

The usable life of wire insulation is directly related to temperature. As a general rule, lowering the temperature 10°C will double the nominal life of the insulation. Conversely, raising the temperature 10°C will half the life. However, in voltages below 600 V, total generator life is not appreciably affected by reduced insulation temperatures.

MG 1-22.41 Maximum Momentary Overloads

Synchronous generators shall be capable of carrying a one-minute overload of 50% of normal rated current with the field set for normal rated load excitation.

MG 1-22.42 Maximum Deviation Factor

The deviation factor of the open-circuit, line-to-line terminal voltage of synchronous generators shall not exceed 0.1.

MG 1-22.43 Telephone Influence Factor (TIF)

kV•A Rating of Generator	TIF Balanced
62.5 to 299	350
300 to 699	250
700 to 4999	150

MG 1-22.45 Short-Circuit Requirements

A synchronous generator shall be capable of withstanding, without injury, a 30-second,

3-phase short circuit at its terminals when operating at rated $kV \cdot A$ and power factor, at 5% over voltage, with fixed excitation.

MG 1-22.46 Overspeeds

Salient-pole synchronous generators shall be so constructed that in an emergency they will withstand an overspeed of 25% without mechanical injury.

Generator Selection

The generator must have the capability of supplying the $kV \cdot A$ demanded by the load without overheating. Further, it must supply sufficient $skV \cdot A$ to start large motors and other inductive devices with low power factor loads.

The generator regulator design must be compatible with the engine/generator package, with most modern generators utilizing solid-state types. The constant voltage regulator allows field forcing to the saturation point to maintain line voltage but has a major disadvantage. It will allow the engine to be overloaded to the extent that it will not recover on application of large block loads.

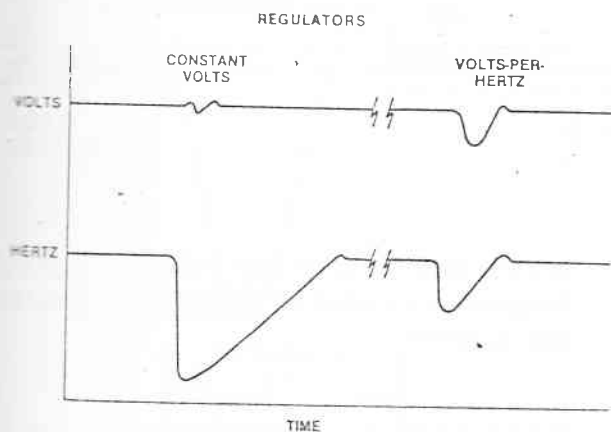


Figure 30

The volts-per-hertz regulator directs the voltage to follow the frequency proportionally, allowing the engine to recover from large block loads more readily. The small amount of voltage change which occurs with normal frequency change (speed droop) can be overcome by adjustment of the gain control (positive feedback).

The mechanical voltage regulator common in older installations is seldom used today due to relatively slow response and high maintenance. It is basically a variable resistor (wire or carbon) in the exciter control circuit.

Single Bearing

The single-bearing generator has its rotor supported at the rear by a bearing supported by the generator frame. The front of the rotor is supported by the engine flywheel. This allows the use of a modest coupling and simple alignment procedures. There is a limit on the amount of weight which can be supported by the flywheel. Rotor weight must be compared to the capability of the specific engine.

The generator flange is bolted to the engine flywheel housing. Torque reaction between the engine and generator can be absorbed at this joint, so a relatively light mounting base can be used. A torsional vibration analysis is required to assure compatibility between the engine and a generator other than Caterpillar.

Two Bearing

This design utilizes the generator frame to totally support the rotor, but alignment is critical. Unless the unit is close coupled (engine flywheel housing bolted to generator bell housing) to the engine flywheel housing, torque reaction is transmitted to the base. The base must have sufficient rigidity to withstand this force without deflecting. In either the conventional or close coupled design, a torsionally resilient

coupling is used between crankshaft and rotor.

CONTROLS

Governors

The governor controls the speed of the engine and, in turn, the frequency of the generator. To select the correct governor for a particular application, the governor's capabilities must be understood. The following

terms are commonly encountered when describing governor characteristics:

Droop, Speed Droop or Regulation — terms used interchangeably to describe the relationship of engine speed and load in steady state operation.

% of Droop/Regulation =

$$\frac{\text{Speed at 0 Load} - \text{Speed at Full Load}}{\text{Speed at Full Load}} \times 100$$

The graph below describes various degrees of droop. The droop curve will remain constant and independent of an operator speed change.

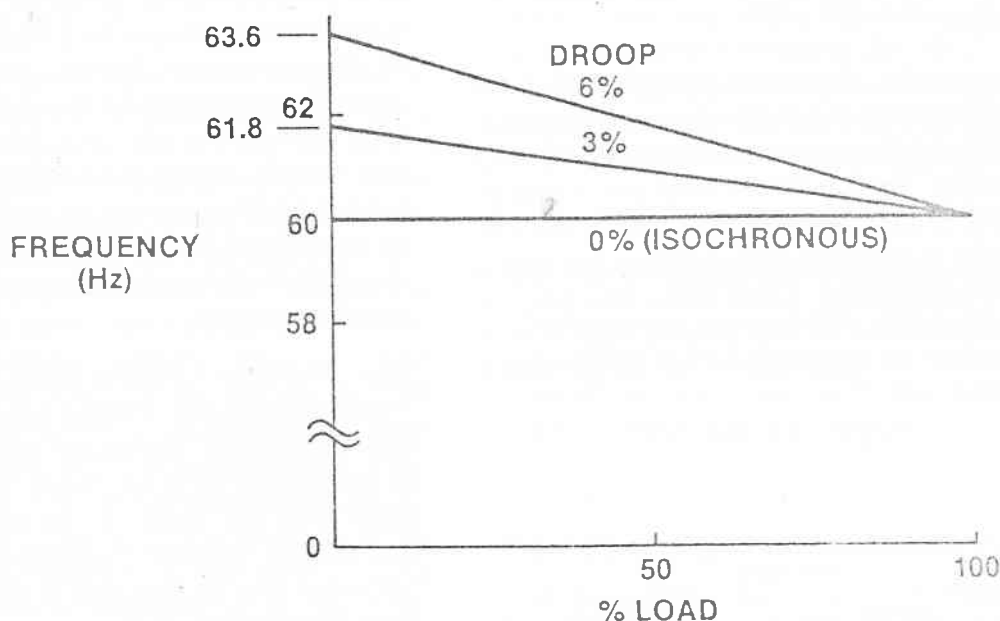


Figure 31

Most applications, particularly those in use as standby, can easily accept 3% speed droop. This allows the use of a less costly and simpler governor and retains the capability of paralleling with other units.

Isochronous — A condition of 0 percent droop, i.e., speed does not change from 0 load to full load. This capability is required

with a varying load which demands precise frequency control or an automatic paralleling system.

Compensation — A method of feedback or damping which will allow stable engine operation with minimum droop. This feature adds sophistication and cost to the system.

Speed Sensing — Using engine speed as control input. All diesel engines are speed sensing in some form.

Obviously, a governor should provide a stable speed control when the load remains constant.

This is unrelated to any particular speed, but is merely a tolerance on speed at any

steady load. Caterpillar governors have a speed tolerance of $\pm 0.33\%$, while Woodward governors offer $\pm 0.25\%$

Transient speeds are temporary excursions from steady-state speeds caused by the sudden imposition or detracting of load.

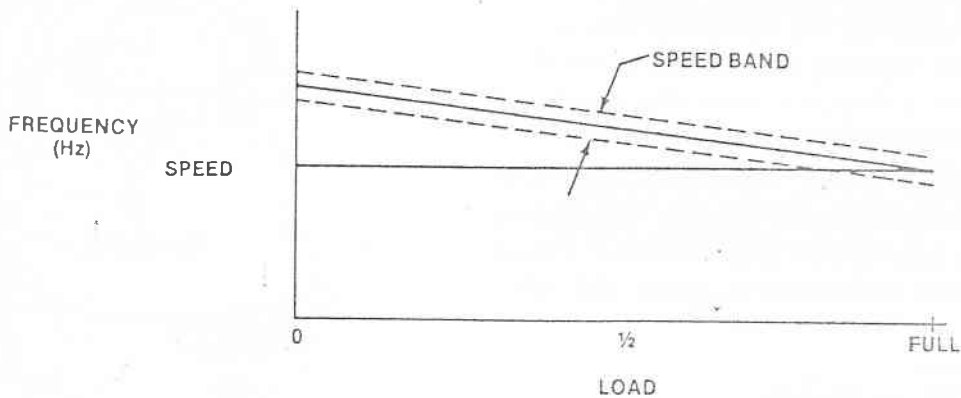


Figure 32

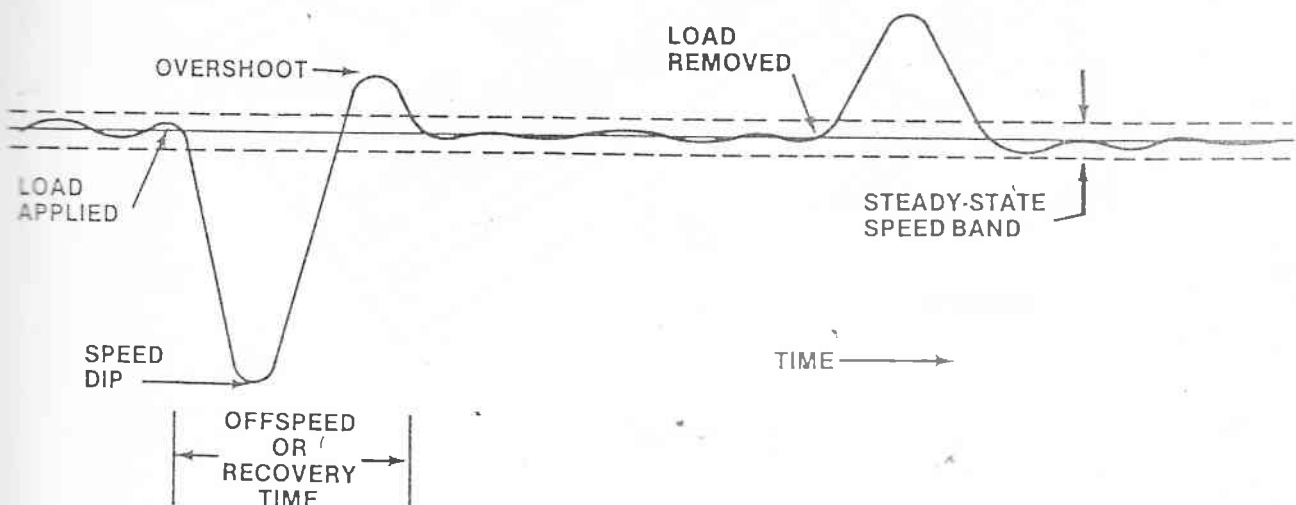


Figure 33

Governor design is only one of the factors which affect transient speed and response. Size of load, engine configuration, and rotating inertia of the engine and generator are all major influencers of the engine's recovery capabilities.

Types

The following types of governors are noted in order of cost, simplicity, and power output. Use the simplest governor which will adequately satisfy the application.

Caterpillar (Figure 34)

Three percent droop, nonadjustable, with manual speed control. Engine lubricating oil used for lubrication and hydraulic power. Used in most installations under 500 kW.

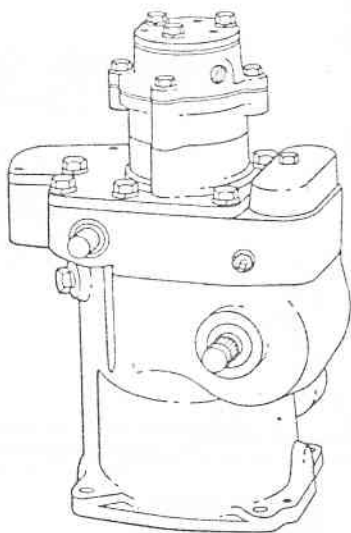


Figure 34

Woodward

PSG: (Figure 35)

Zero percent (isochronous) to seven percent droop, externally adjustable, with synchronizing motor for remote speed control. Engine lubricating oil used but contains internal pump.

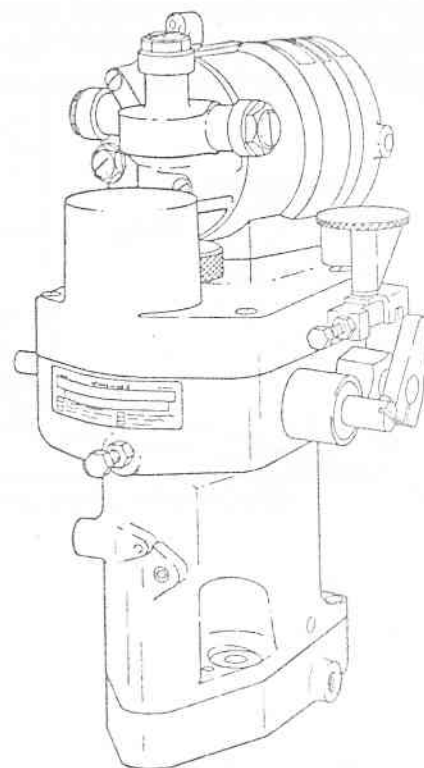


Figure 35

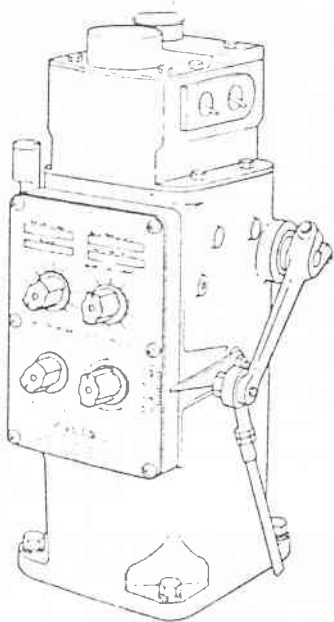


Figure 36

UG8 (Dial) (Figure 36)

Zero percent (isochronous) to ten percent droop, externally adjustable, with synchronizing motor for remote speed control. Adjustable load limit. Uses own oil supply and pump which develops output force necessary to control large engines.

2301/EG3P: (Figure 37)

Electronic governor, 0 percent (isochronous) to 10 percent droop. System includes magnetic speed pickup, control for parallel/non-parallel operation and actuator using engine lubricating oil and internal pump. Applied where extreme frequency control is demanded or in automatic paralleling installations. Figure 38 describes the wiring connections necessary when applying a 2301/EG3P governing system.

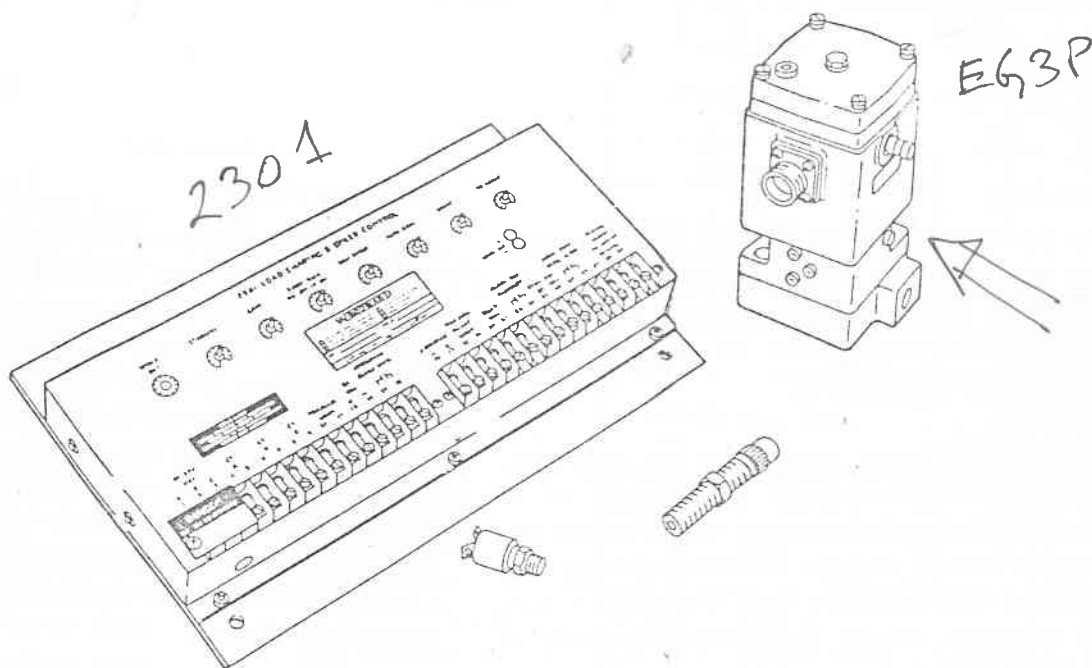


Figure 37

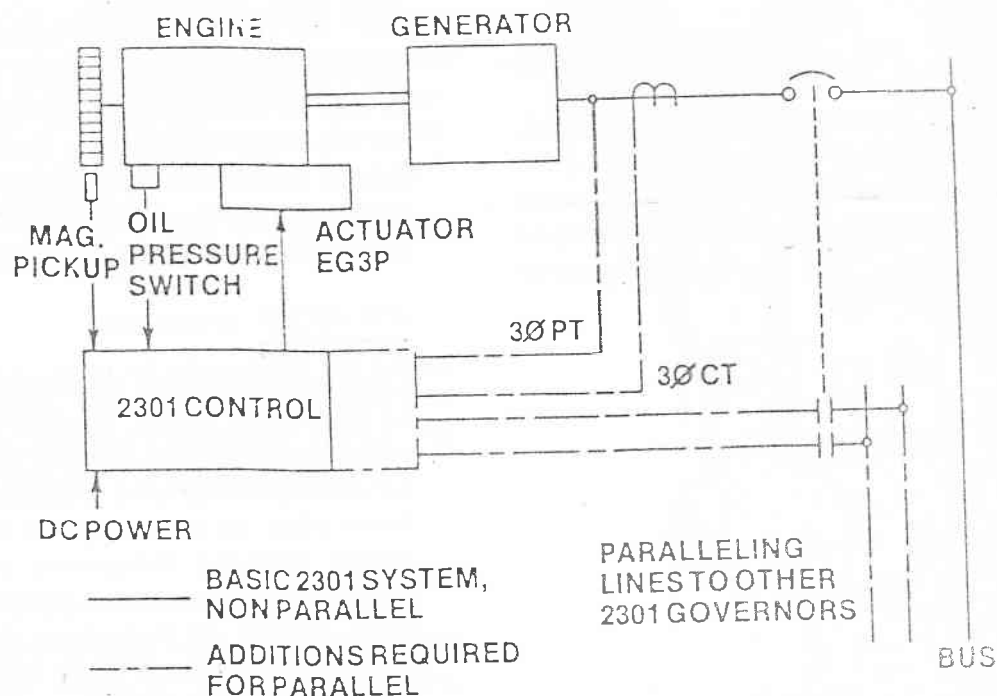


Figure 38

Start-Stop

The complexity of start-stop controls will vary according to the application and the caliber of operating personnel. There are two general categories of installations: manual and automatic.

The operator must determine the appropriate time to disengage the starter in a manual system. Cranking logic must be used to sense engine starting unless the operator is physically near the engine during starting. In an automatic system, a cranking panel incorporates this ability.

Manual control systems require relatively simple controls. With competent operators, the least complex switchgear will result in the most reliable system, particularly when supported by automatic engine shutdown devices.

Cranking Panel

The cranking panel is the logic circuitry, or intelligence, of the starting system. The cranking panel can be unit-mounted, wall-mounted, or installed into another control system. When given a signal, the cranking panel will engage the cranking motor on the engine, disengage the motor when the engine fires, and after the engine is running will monitor the conditions which are critical to the engine's operation. It should include an annunciator system for visual and/or audible signals.

By design, the cranking panel will allow the engine to crank for a given duration of time; it can also include timers to allow shorter cycles of cranking, with rest periods between the cranking cycles. Single cranking periods should not be longer than 30 seconds. Cycle cranking timers can generally be adjusted to give 10 seconds of cranking

time with a 10-second rest period between cranking cycles, with a maximum of four to five cranking periods. The merits of cycle cranking on a diesel engine are questionable. Generally, a diesel engine will start within the first cranking period or will not start at all. Further cranking attempts will probably only serve to discharge the cranking batteries. The reason for hard startability should be investigated before further starting attempts are made.

Shutdown Devices

Minimum protection for any generator set should include low lubricating oil pressure,

high water temperature, and overspeed shut-downs. If remotely started, an overcrank protection is needed. An indication of engine water level and flow is also desirable, either for a warning or shutdown. Any number of equipment operating parameters can be monitored depending upon individual installation requirements.

The following schematic represents a typical automatic start-stop control utilizing an electric solenoid shutdown.

SCHEMATIC OF CONTROL PANEL
CONTROLS IN AUTOMATIC POSITION: STANDBY CONDITION

ABBREVIATIONS

A	AMMETER	OPG	OIL PRESSURE GAUGE
ACS	ENGINE CONTROL SWITCH	OPIR	LOW OIL PRESSURE
ALT	CHARGING ALTERNATOR		INDICATING RELAY
AR	ARMING RELAY	OPS	OIL PRESSURE SWITCH
ARY	AUXILIARY RELAY MODULE	OSIR	OVERSPEED INDICATING
AUX	AUXILIARY CONTACT		RELAY
BATT	BATTERY	OSS	OVERSPEED SWITCH
B+	BATTERY POSITIVE	PIL	PANEL ILLUMINATION LAMP
B-	BATTERY NEGATIVE	PLS	PANEL LAMP SWITCH
CB	CIRCUIT BREAKER	PS	PINION SOLENOID
CCM	CYCLE CRANKING MODULE	PSW	PRESSURE SWITCH
CCT	CYCLE CRANK RELAY	RE	FAULT RESET SWITCH
CRC	CYCLE CRANK LOGIC TIMER		PART OF ENFL
CT	CURRENT TRANSFORMER	RR	RUN RELAY
D	DIODE	SM	STARTING MOTOR
ENFL	ENGINE FAULT LIGHT WITH	SR	SHUTDOWN RELAY
	FAULT RESET FUNCTION	SS	SHUTOFF SOLENOID
GP	GLOW PLUGS	USS	UNDERSPEED SWITCH
GS	GOVERNOR SWITCH	WT	WATER TEMPERATURE
GSM	GOVERNOR		GAUGE SENDER
	SYNCHRONIZING MOTOR	WTG	WATER TEMPERATURE
HS	GLOW PLUG HEAT SWITCH		GAUGE
	REMOTE START INITIATING	WTIR	HIGH WATER TEMPERATURE
	CONTACT		INDICATING RELAY
MS	MAGNETIC SWITCH (CRANK	WTS	WATER TEMPERATURE
MSG	MAGNETIC SWITCH (GLOW		SWITCH
	PLUG CIRCUIT)		
OCIR	OVERCRANK INDICATING		
	RELAY		
OCT	OVERCRANK TIMER		
OP	OIL PRESSURE GAUGE		
	SENDER		



TERMINAL STRIP POINT
(CONTROL PANEL)



TERMINAL STRIP POINT
(GENERATOR TERMINAL
BOX)

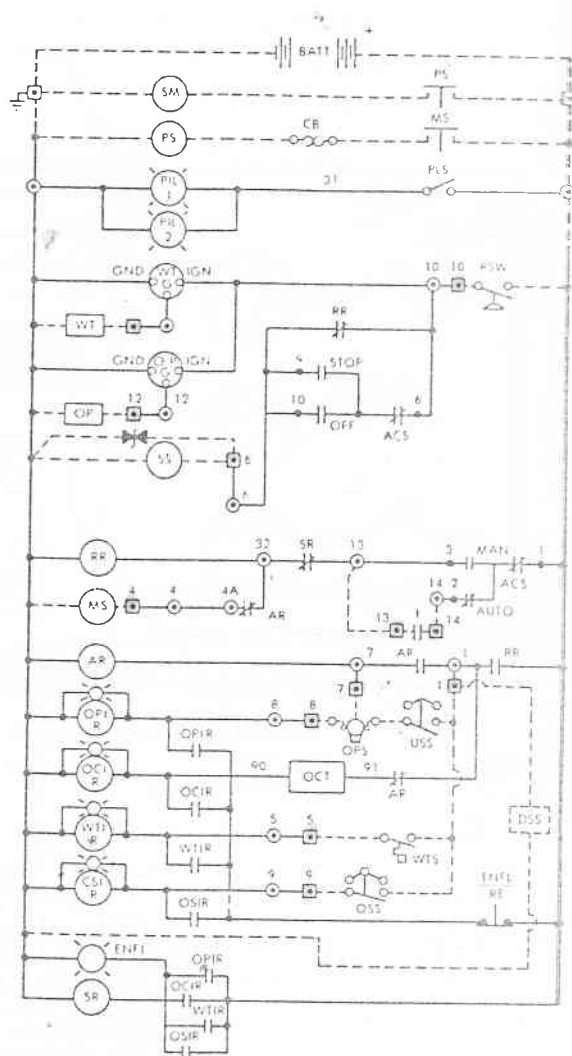


Figure 39

The cranking panel can include prealarms which will, in conjunction with engine-mounted sensors, monitor deteriorating operating conditions. Prealarms can be effectively used in critical installations to indicate a deteriorating condition before a shutdown. This will allow operating personnel to remedy the situation and prevent unnecessary stoppage of the unit.

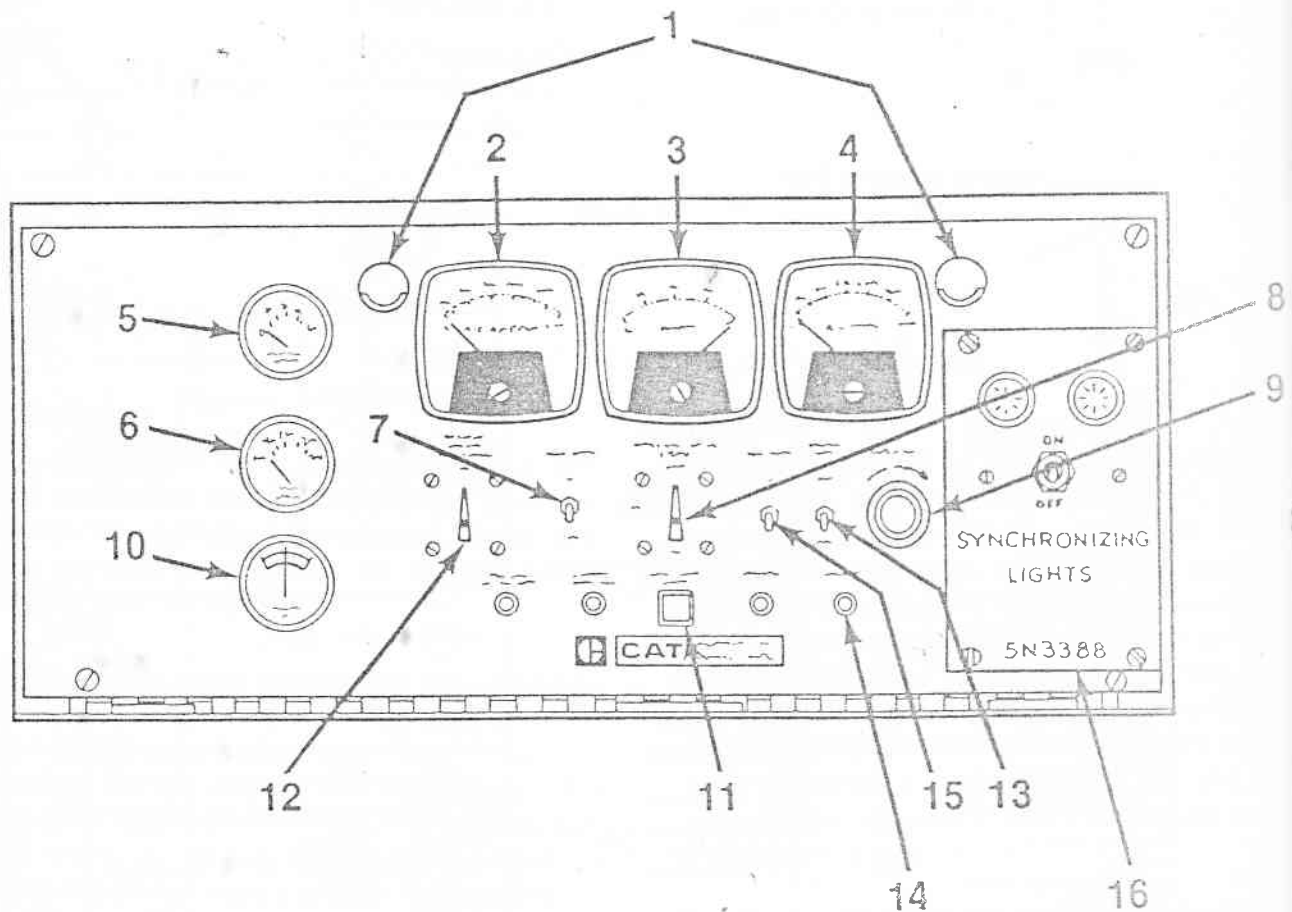
A cool down timing circuit is recommended which will allow the engine to operate under no load conditions for at least two minutes before normal shutdown.

SWITCHGEAR

Types

Control panels normally incorporate both cranking panel functions and engine and generator instrumentation. They may, according to their bulk and complexity, be mounted on the generator set or remote-mounted on a wall or floor. This generator-mounted panel displays equipment typical for a unit in parallel application.

CONTROL PANEL



1. Panel lights. 2. Alternating current ammeter. 3. Frequency meter. 4. Alternating current voltmeter. 5. Oil pressure gauge. 6. Water temperature gauge. 7. ON/OFF toggle switch for panel lights. 8. Engine control switch. 9. Voltage level rheostat. 10. Button (direct current ammeter is ordered). 11. Engine failure light/reset switch. 12. Ammeter selector switch. 13. Button (governor control switch if engine is equipped with a PSG governor). 14. Shutdown indicators for pressure, water temperature, overspeed and overcrank. 15. Button; Heat switch (if so equipped). 16. Synchronizing lights.

Figure 40

Floor standing panels allow room for more complex controls and/or components which carry higher currents. A minimum working area of one meter will allow access to the rear of the switchgear, while provisions must be made for the entrance and exit of power and control leads. A typical floor standing control is shown below.

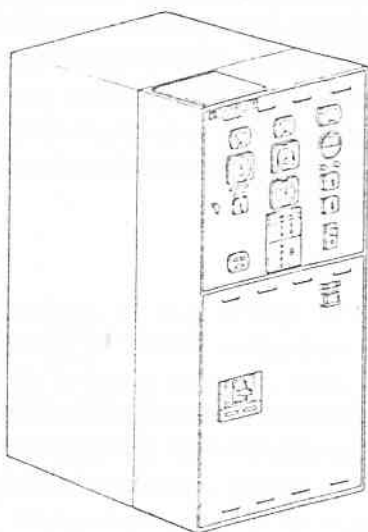


Figure 41

Remote switchgear offers some advantages if located in a separate room. Although switchgear can operate in an engine room atmosphere, service life can be greatly improved by mounting in a clean, dry, and well ventilated room with a maximum temperature of 85°F (30°C). It is also beneficial to filter incoming air and maintain the room under a slight pressure to encourage cleanliness.

The annunciators for the prealarms can be incorporated into the main control panel and, if required, may also notify a remote location.

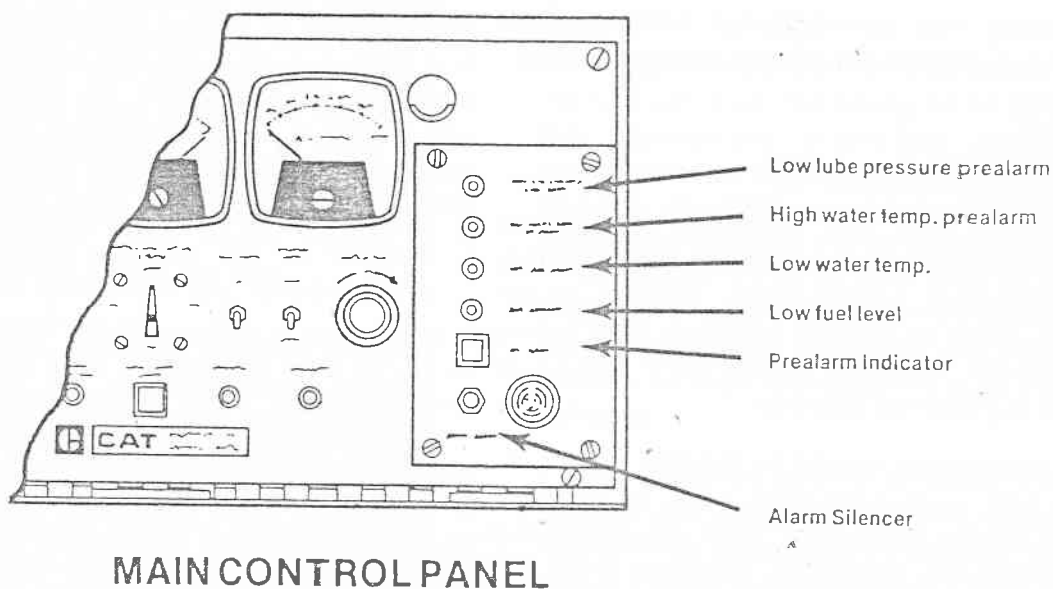
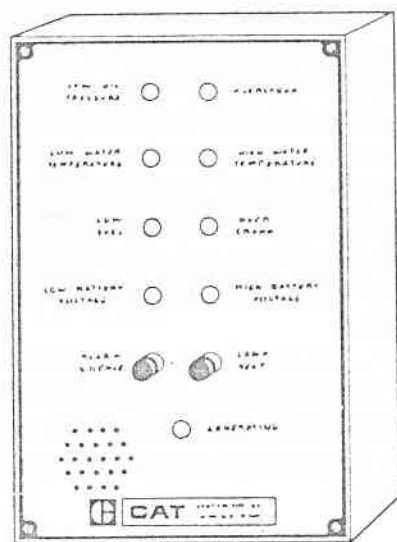


Figure 42



REMOTE ANNUNCIATOR PANEL

Figure 43

A shunt trip, which allows tripping of circuit breakers from a remote location either by an operator or an alarm signal, may be a worthwhile addition. Closing the breaker from a remote location can also be accomplished by addition of a motor operator or replacing the conventional breaker with one incorporating a stored energy device.

Ambient Conditions

Excessive heat, dirt, moisture, or contaminated atmosphere can reduce the reliability of electronic components. Certain equipment, such as circuit breakers and fuses, will begin derating above 95°F (40°C) or 6,000 ft (1800 m) altitude.

The switchgear should be located in a clean, dry, and well-ventilated area. In installations where generator sets are operating continuously, complete isolation in an air-conditioned control room may be appropriate. Adequate working area must be provided to gain access from both the front and rear of the panels.

CIRCUIT PROTECTIVE DEVICES

The maximum amount of fault current supplied by a system can be calculated at any point in that system. The interrupting capacity of the overcurrent device must be equal to or greater than the amount of fault current that can be delivered at that point in the system where the breaker is applied.

The maximum short circuit current which a generator can produce is only slightly affected by regulation design and is the product only of the electrical properties of the generator. The maximum three-phase short circuit current which can be developed by a generator is:

$$I_{sc} = \frac{E_{ac}}{x''d}$$

E_{ac} = open circuit voltage

$x''d$ = direct axis subtransient reactance

A Caterpillar Generator will typically produce eight times its rated current on a three-phase fault. If generators are in parallel, or if paralleled to a utility bus, the overcurrent devices must withstand the total short circuit current developed by all generating devices. Synchronous and induction motors will feed additional short circuit current to the fault at a value approximately equal to their locked rotor rating. If a circuit breaker is used, an additional protective device upstream of the breaker may be required when connected to a utility bus.

Without outside influence, the short circuit current developed by the generator will decay within three to five cycles and fall below the activating range of the overcurrent device Figure 44. While the clearing time of circuit breaker contacts may range from 1-1/2 to 3 cycles, the actual unlatching time for a circuit breaker is less than 1 cycle. This rapid reaction time will allow the breaker to trip from the current developed by the generator.

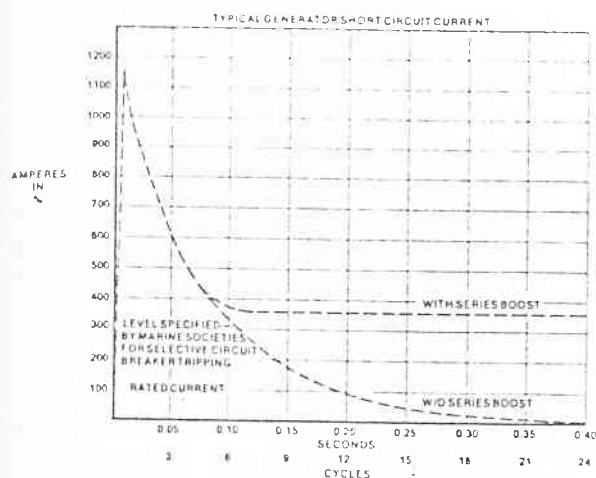


Figure 44

The coordination, or selectivity, of all overcurrent devices in the distribution system is required to protect against total system failure on short circuit faults. When this capability is required, both overcurrent devices and generator characteristics must be expanded. The circuit breaker or fuse must include a short time delay. A fused circuit is usually preferred for precise circuit coordination. The delay between unlatching and actual clearing of the overcurrent is the major obstacle in coordinating breakers. This delay also allows the current to flow through the breaker until the contacts can clear and extinguish the arc. In a poorly coordinated system with several breakers in series, the larger upstream breaker may start to unlatch prior to the fault being cleared by the smaller breaker. This could result in a blackout of the entire system.

The generator must continue to supply a high current level during the fault to allow time for coordinating all of the protective devices. The actual time required is usually less than three seconds, but certain marine classification societies have specified a minimum of 10 seconds for maintenance of current levels 300% above rated. The generator requires a series boost option on the regulator circuit to satisfy these requirements. Figure 44 describes the effect to

the series boost option on a typical decrement curve.

A partial ground may cause a current flow sufficiently large to cause damage if left undetected, but below the current rating of the overcurrent protective device. To guard against this type of fault, ground fault protective devices must be used. They sense the abnormal current flow, and clear the circuit by means of the shunt trip on the circuit breaker or switch.

These devices are usually set to respond to current flows of 50 to 400 amperes, depending on the load characteristics of the circuit and the equipment to be protected. Nuisance tripping due to normal changes in load current must be avoided. Unwanted tripping may also be caused by SCR loads, which may prove incompatible with ground fault protective devices.

The system described only pertains to equipment protection, and affords no protection to personnel. Medical research has established that a current as little as 7-1/2 milliamps is sufficient to arrest the heart muscle.

Comparisons of Fuses And Circuit Breakers

The specific requirements for each electrical system must be analyzed to determine the overcurrent protection device best suited for the application. In some cases, not only must the system be safe under all service conditions, but to ensure continuity of service, it must be selective as well. An intelligent selection and/or combination of fuses and circuit breakers will result in a system of maximum safety with minimum outages.

Each protective device is offered in many designs and exhibits overlaying capabilities. A simplistic comparison has been made only of the most basic devices. Fuses are considered to be dual element with high interrupting capacities. Circuit breakers are the 3-pole thermo-magnetic molded case type.

Fuses (Including Switch)

Advantages	Disadvantages
Simple	Switch Required
Fireproof	Nonresetable
Precise Characteristics	Nonreusable
Initial Economy	Nonadjustable
Very High Interrupt Capability	Nonindicating
High Current Limiting	Single Pole Only*
No Maintenance	
Fast Opening	

*Normally a disadvantage because single-phasing of three-phase motor may occur. May be advantage in emergency conditions where limited power is desired even when one phase is inoperative.

Circuit Breakers

Multipole	Complex Construction
Small, Convenient	Periodic Maintenance
Resetable	High Initial Cost
Mode Indicator	Medium Interrupt Capability
Testable	
Adjustable	
Auxiliary Contacts	
Multi-Options — Remote Control	

Fuse

The application of fuses for overcurrent protection in electrical systems is considerable, particularly in other parts of the world. Various types are available, and selection should be made after considering:

1. Voltage Rating

The voltage rating for a fuse should be equal to or greater than the voltage of the circuit in which the fuse is applied. This rating is not a measure of its ability to withstand a specified voltage while carrying currents. Rather, it defines the ability of the fuse to prevent the open circuit voltage of the system from re-striking and establishing an arc once the fuse link has parted.

2. Continuous Current Rating

The continuous current rating should be equal to or slightly greater than the current carrying capacity of the circuit which it protects. Only in special cases where the connected equipment has unusual characteristics or where the ambient temperature is quite high should the fuse rating be greater than the current carrying capacity of the circuit.

3. Interrupting Rating

For power application under 600 V, high-quality fuses which have a 200,000 rms symmetrical ampere interrupting rating are adequate for large power systems. Electronic applications usually require a small dimension fuse which will have an interrupting rating sufficient for the application.

4. Degree of Current Limitation

Fuses for circuits containing motors, transformers, or any inductive device are usually dual element Figure 45. This provides a time delay section to carry inrush current which opens after a specified delay for overload protection. A second section of the fuse is provided to limit the high energy of a short circuit.

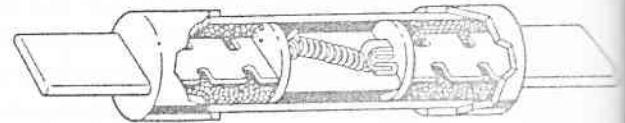
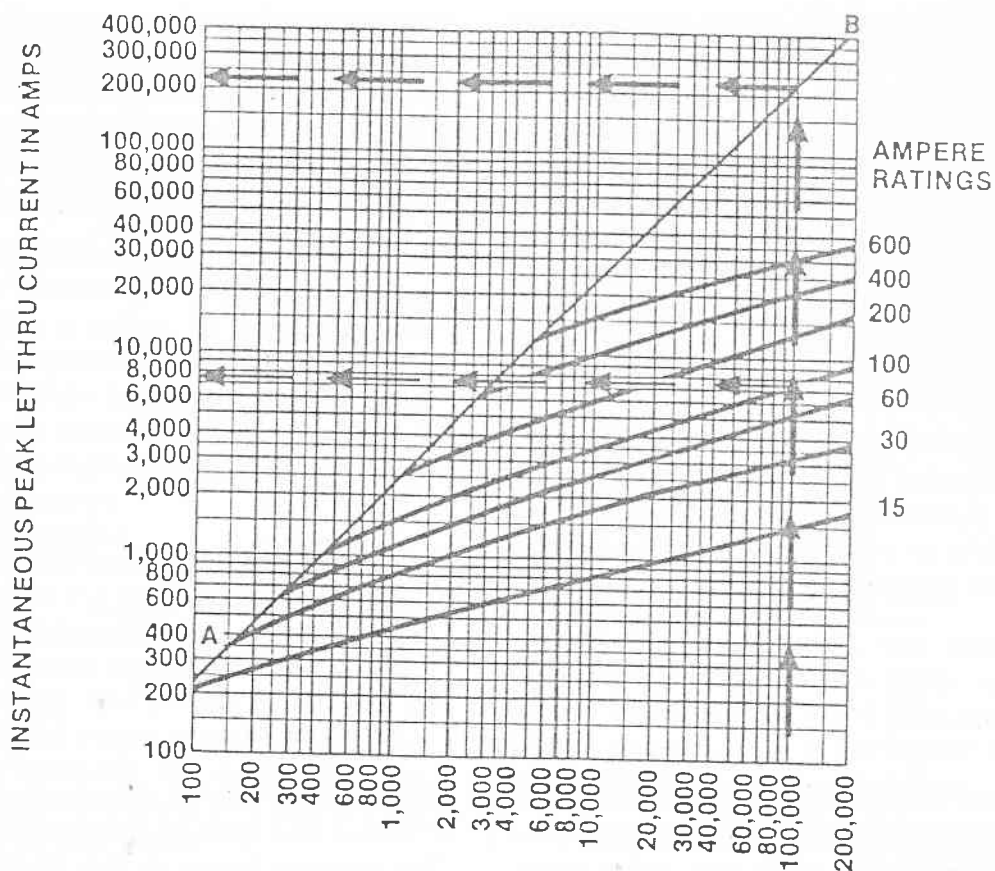


Figure 45

Circuit breakers are often protected by fast-acting fuses because of their high degree of current limitation. The fuse limits the short-circuit current to a value which can be safely absorbed by the breaker or other system component. This ability is particularly important when the circuit is being paralleled to a large power source such as a utility. It is also used for meter and instrument protection.

The graph in Figure 46 illustrates the current limiting properties of a fast-acting fuse. In the example, the rms value of a potential short-circuit current, calculated from circuit constants, is 100,000 amperes symmetrical. From the intersection of this value with line A-B, the instantaneous peak value is 230,000 amperes. If a typical 100-ampere fuse were used in the circuit, the peak let-through current approximates 7,500 amperes — about 4% of the current that would flow if the fuse were not protecting the circuit.



PROSPECTIVE SHORT CIRCUIT CURRENT — SYMETRICAL RMS AMPS

Figure 46

Electronic circuits which may carry transient currents use time-delay type fuses. They will open quickly on a short, but still retain circuit integrity for normal current fluctuations.

Circuit Breaker

A circuit breaker is a device designed to open and close a circuit by nonautomatic means and to open the circuit automatically on a specific overcurrent without damage to itself. The most common type is the molded case breaker, which is assembled as an integral unit in a supporting and enclosing housing of insulating materials. It protects low voltage distribution systems against overloads and/or short circuits.

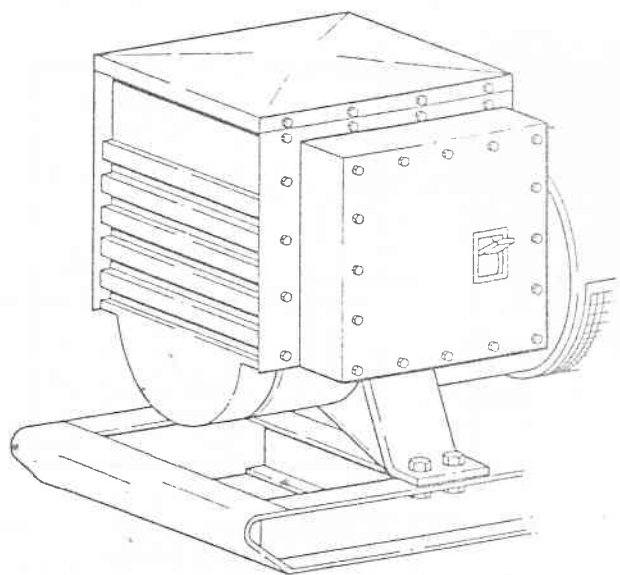
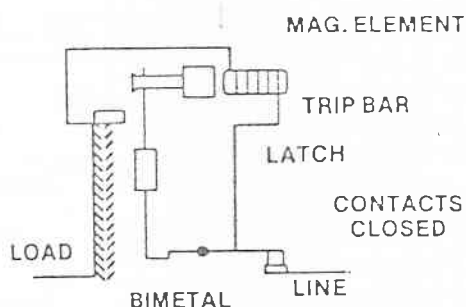


Figure 47

Generator field breakers, which cause a loss of excitation, are useful as a generator disconnect device but are not considered adequate main line disconnect devices. Circuit breakers have an advantage over fusible elements in that a fault on one pole of a multi-pole breaker activates a common trip bar that opens all poles simultaneously.



Conventional breakers are referred to as thermomagnetic type. They utilize a bi-metal strip which will deflect with sustained overload, and an electromagnetic coil which is activated by a high short-circuit current. Either of these devices will open all poles of the breaker.

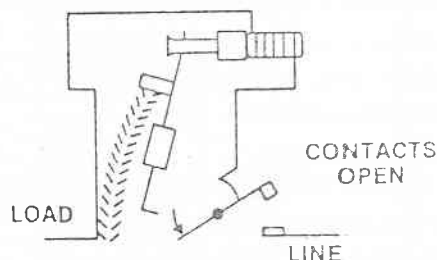


Figure 48

Breakers are available with either a fixed or interchangeable electromechanical trip unit. The interchangeable units are most common and have the added flexibility of adjustable magnetic elements. The thermal setting is fixed. A typical trip curve for a Westinghouse 100 amp thermomagnetic breaker is shown, depicting the dual element trip characteristic.

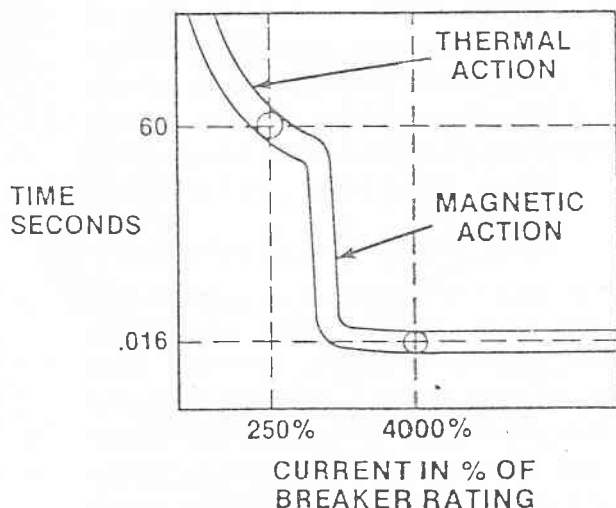


Figure 49

Molded case circuit breakers are rated in amperes at a specific ambient temperature. This ampere rating is the continuous current the breaker will carry in the ambient temperature for which it is calibrated. Most manufacturers calibrate their standard breakers for a 104°F (40°C) ambient.

The interrupting rating of the breaker is the maximum amount of fault current it can interrupt without damaging itself.

A shunt trip is a useful device used to trip the circuit breaker from a remote location. It uses an AC/DC electrical signal initiated by a pushbutton or a contact closing as a result of an engine/generator malfunction. To reclose the breaker after operation of the shunt trip, the breaker handle must be manually reset.

A motor operator allows remote opening and closing of the breaker by engaging an operator arm on the manual handle. The generator arm is then positioned by motor action. The motor operator is intended only for infrequent use in line with UL endurance standards for molded case breakers. The life of a breaker is generally considered

to be adequate to withstand a minimum of 6,000 cycles at rated load and an additional 4,000 cycles at no load.

AUTOMATIC TRANSFER SWITCH

The function of an automatic transfer switch is to transfer electrical loads from a normal source, usually a utility, to an emergency source, often a generator set, when the normal source voltage fails or is substantially reduced. When normal power is restored, the switch automatically retransfers back to the normal source.

The switch senses a power interruption and sends a signal to the engine cranking panel to start. It monitors voltage and frequency, when the generator develops rated values, transfers the load. The switch continues to sense the normal power supply. When normal power is restored, the switch retransfers back to normal supply and signals the generator set to shut down.

The time required to switch from one power source to another can be extremely short. A transfer switch can typically complete this action in less than six cycles. Caution must

be used when transferring loads which include large motors, particularly synchronous motors or those driving high inertia equipment. When disconnected from the power source, the magnetic flux developed by these motors temporarily maintains voltage. This can cause serious mechanical or magnetic problems as a power source is reconnected. It can be compared to out-of-phase paralleling and produce transient torques ten times that of rated.

To avoid this problem, delay transfer whenever possible until residual voltage is less than 25% of rated. Synchronous motors should be removed from the line and remain disconnected until their rotation ceases.

In a standby application, the emergency generator set requires five to ten seconds to start and develop rated frequency and voltage. Usually, this is sufficient time for the regenerative voltage to decay.

On retransfer back to normal power, this out-of-phase condition must again be avoided. When a rapid transfer is required, the emergency power source must match voltage, frequency, and phase angle as transfer takes place.

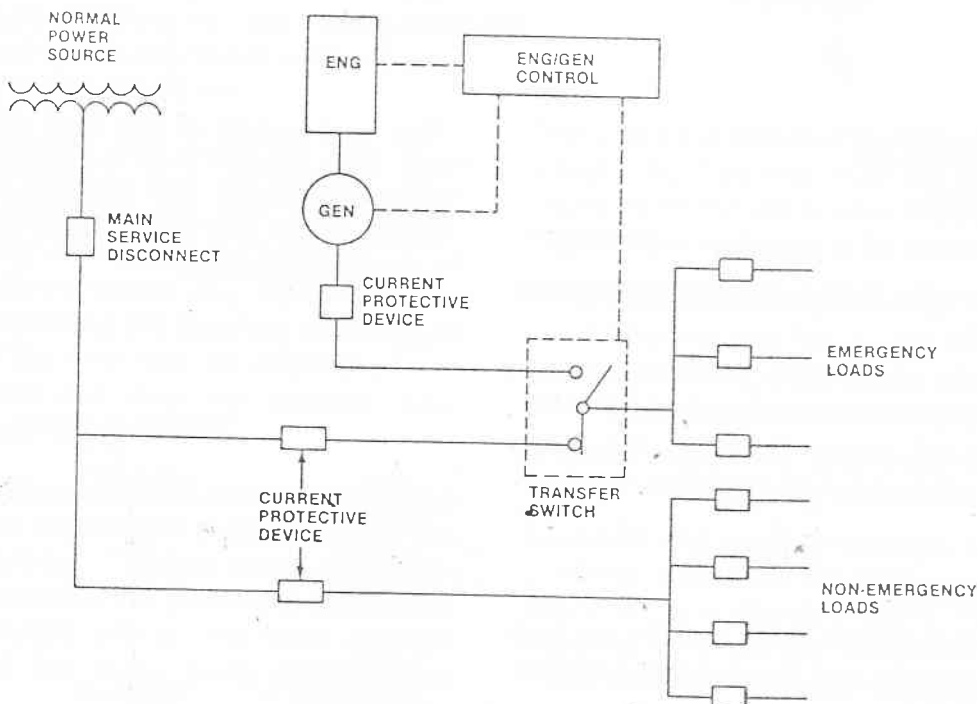


Figure 50

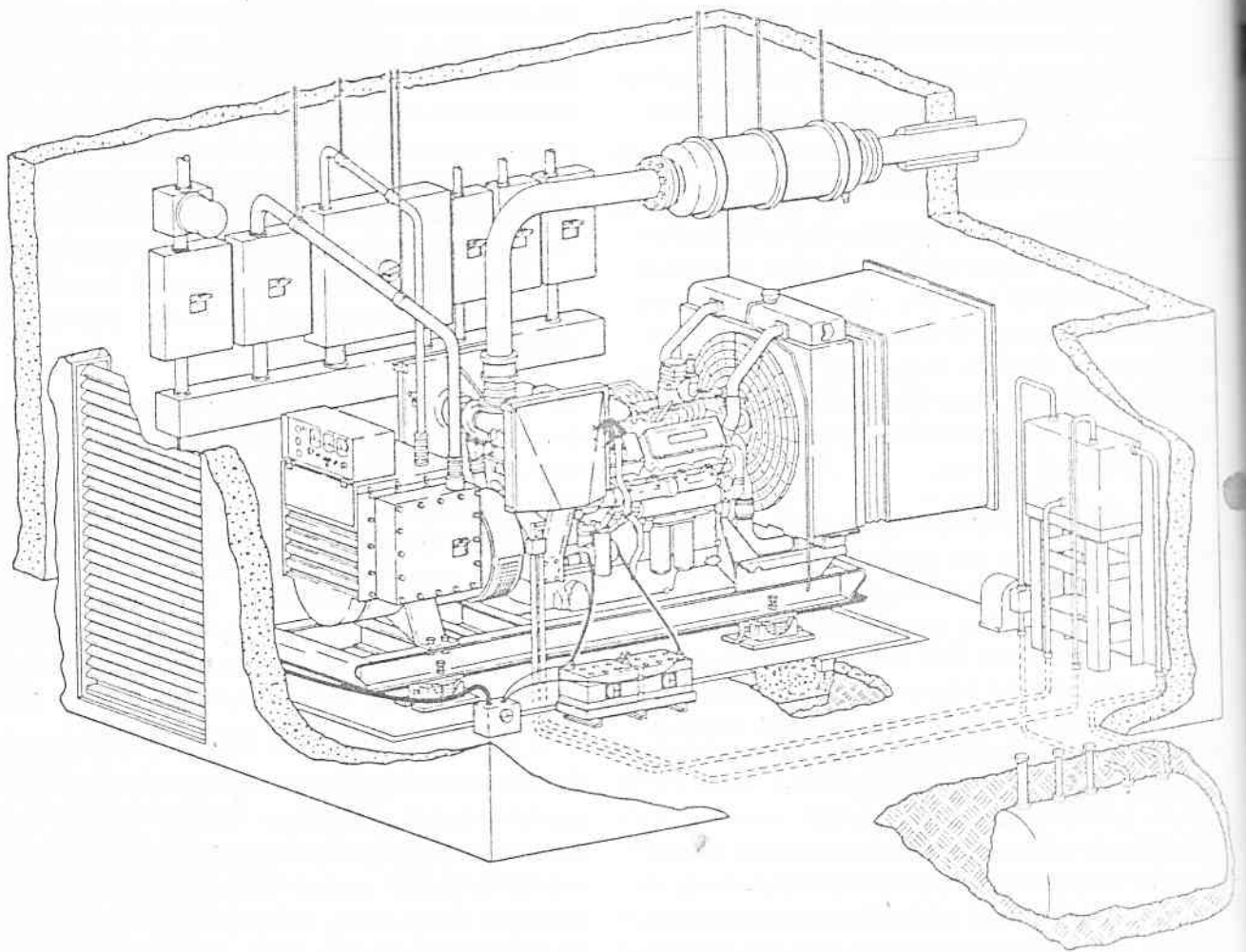


Figure 51

INSTALLATION

FOUNDATION

Major functions of a foundation are to:

- Support the total weight of the generator set.
- Maintain alignment between engine, generator, and accessory equipment.
- Isolate generator set source vibration from surrounding facilities.

Ground Loading

Initial considerations must include the generator set weight and the material supporting this weight.

The wet weight of the total package must be calculated. This includes accessory equipment and the weight of all liquids, coolant, oil and fuel, which are supported by the foundation.

Weights of Liquids		
Liquid	lb/U.S. gal	Specific Gravity
Water	8.3	1
Lube Oil	7.6	0.916
Diesel Fuel	7.1	0.855
Kerosene	6.7	0.80

Figure 52

The supporting material on which the foundation rests must carry the total weight. Figure 53 notes the bearing load capabilities of typical materials.

Bearing Load Capability

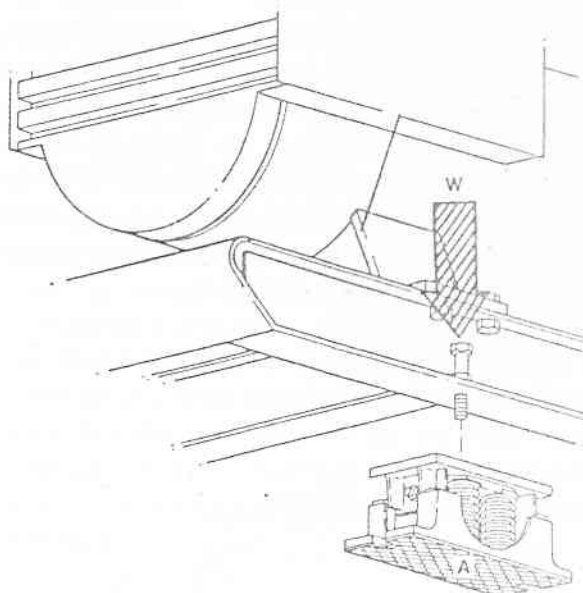
Material	Safe Bearing Load psi	kPa
Rock, Hardpan	70	482
Hard Clay, Gravel and Coarse Sand	56	386
Loose Medium Sand and Medium Clay	28	193
Loose Fine Sand	14	96.4
Soft Clay	0-14	0-96.4

Figure 53

Firm level soil, gravel or rock can provide a satisfactory foundation for a single-bearing generator set used in either stationary or portable service. This type of foundation can be used where the weight-bearing capacity of the supporting material exceeds the pressure exerted by the equipment package and where alignment with external machinery is not important.

Certain types of soil, such as fine clay, loose sand, or sand near the ground water level are particularly unstable under dynamic loads and will require a foundation of substantially increased area. Specific information concerning the bearing capacity of the soil at the site may be available from local sources and must not exceed local building code standards.

The area of the supports which carries the load must be adjusted to accommodate the surface material. To determine the pressure (P) exerted by the generator set, divide the total weight (W) by the total surface area (A) of the rails, pads or vibration mounts.



$$P(\text{psi}) = \frac{W(\text{LBS})}{A(\text{SQ INCHES})}$$

Figure 54

$$P(\text{psi}) = \frac{W(\text{pounds})}{A(\text{inches})^2} \quad kPa = \frac{kN}{m^2}$$

The pressure imposed by the generator set weight must be less than the load carrying capacity of the applicable material noted in Figure 53.

Where the support rails or feet have insufficient bearing area for use on the soil at the installation site, a flotation pad or pads can be used to distribute the weight. The underside area and stiffness of the pad or pads must be sufficient to support the equipment.

Seasonal and weather changes can adversely affect a material mounting surface. Soil can alter considerably while freezing and thawing. To avoid the movement caused by these seasonal changes, foundations should reach below the frost line.

Concrete Base

Several basic foundation designs are applicable for generator sets. The foundation chosen will depend on the factors previously outlined as well as on limitations imposed by the individual location and application. Massive concrete foundations are not necessary for modern multicylinder medium-speed generator sets.

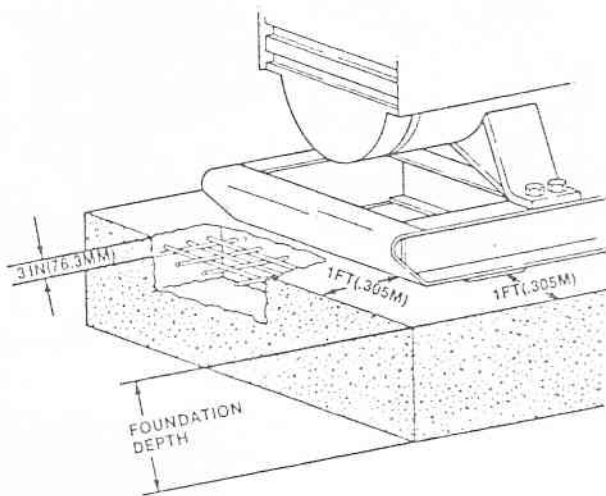


Figure 55

If a concrete foundation is required, some minimum design guidelines to consider are:

- The foundation length and width should exceed the length and width of the generator set a minimum of 1 ft (0.305 m) on all sides.
- The foundation depth should be sufficient to attain a minimum weight equal to the generator set wet weight.

To calculate the necessary foundation depth, use:

$$\text{Foundation Depth (ft)} = \frac{W}{150 \times B \times L}$$

$$\text{(m)} = \frac{W}{2402.8 \times B \times L}$$

W = Total wet weight of generator set (pounds) — (kg)

150 = Density of concrete (pounds per cubic foot)

2402.8 = Density of concrete (kilograms per cubic foot)

B = Foundation width (feet) — (meters)

L = Foundation length (feet) — (meters)

Suggested concrete mixture by volume is 1:2:3 of cement, sand, aggregate with a maximum four-inch — (101.8 mm) slump with a 28-day compressive strength of 3000 psi (27,000 N•m²).

The foundation should be reinforced with No. 8 gauge steel wire fabric or equivalent, horizontally placed on 6 in (152 mm) centers. An alternate method of reinforcing is to place No. 6 reinforcing bars on 12 in (304 mm) centers horizontally. Bars should clear the foundation surface a minimum of 3 in (76.3 mm).

When effective vibration isolation equipment is used, the depth of floor concrete required is that needed for structural support of the static load. If isolators are not used, dynamic loads will be transmitted to the facility floor and the floor must be designed to support 125% of the generator set weight.

If the generator set is to operate in parallel with other units, the possibility of out-of-phase paralleling and resultant increased torque reactions demand a stronger foundation. This foundation must be designed to withstand a weight which is 2.0 times the wet weight of the generator set.

Excessively thick, heavy bases should be avoided since they increase sub-floor or soil loading. They should be only thick enough to prevent deflection and torque reaction, while still retaining sufficient surface area to satisfy the supporting material.

Installation costs can be appreciably reduced when the unit will be operated for a

limited time in a proposed installation. For standby service in a building, a unit can be set on a floor without anchoring.

Fabricated Steel Base

Frequent movement of the generator set, ease of initial installation, vibration isolation, or need of isolating from a flexing mounting surface, such as a trailer, are major reasons for use of fabricated bases. No base of any type should be rigidly connected to a flexing surface. All bases must maintain alignment between engine, generator, and other driven equipment such as radiator fans.

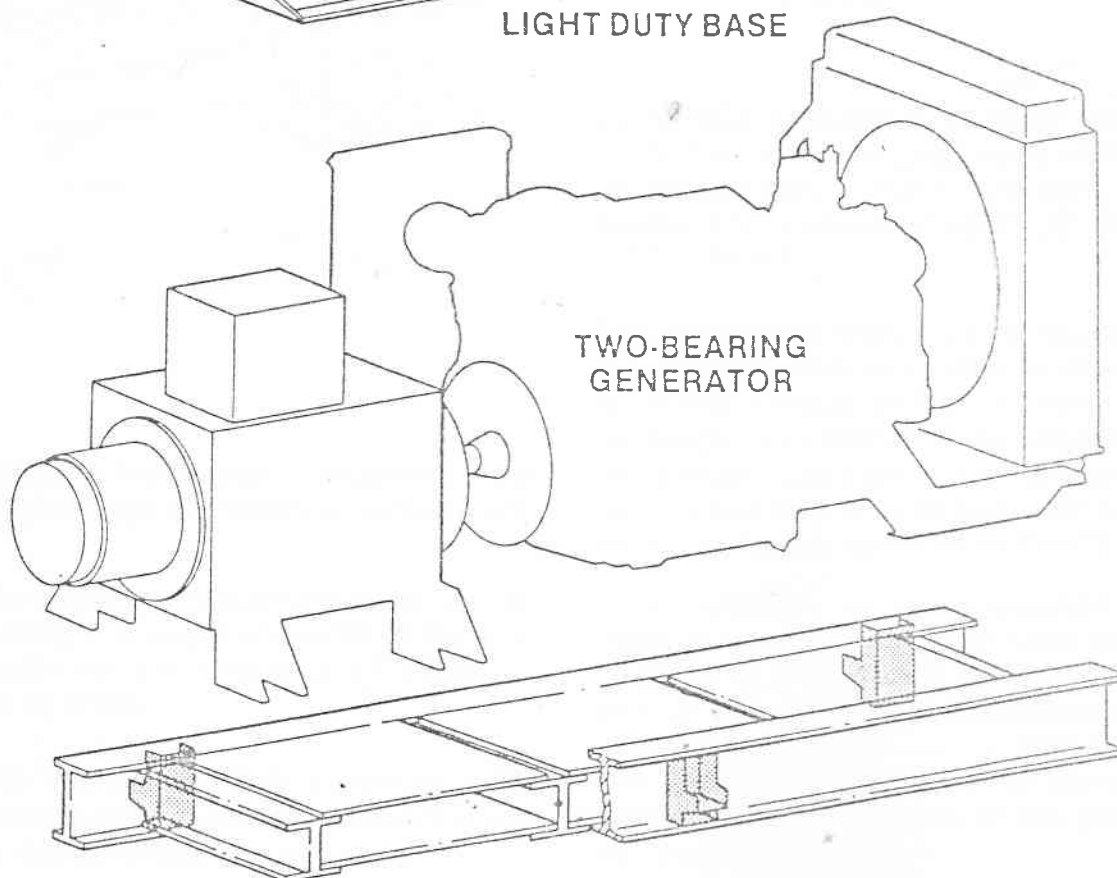
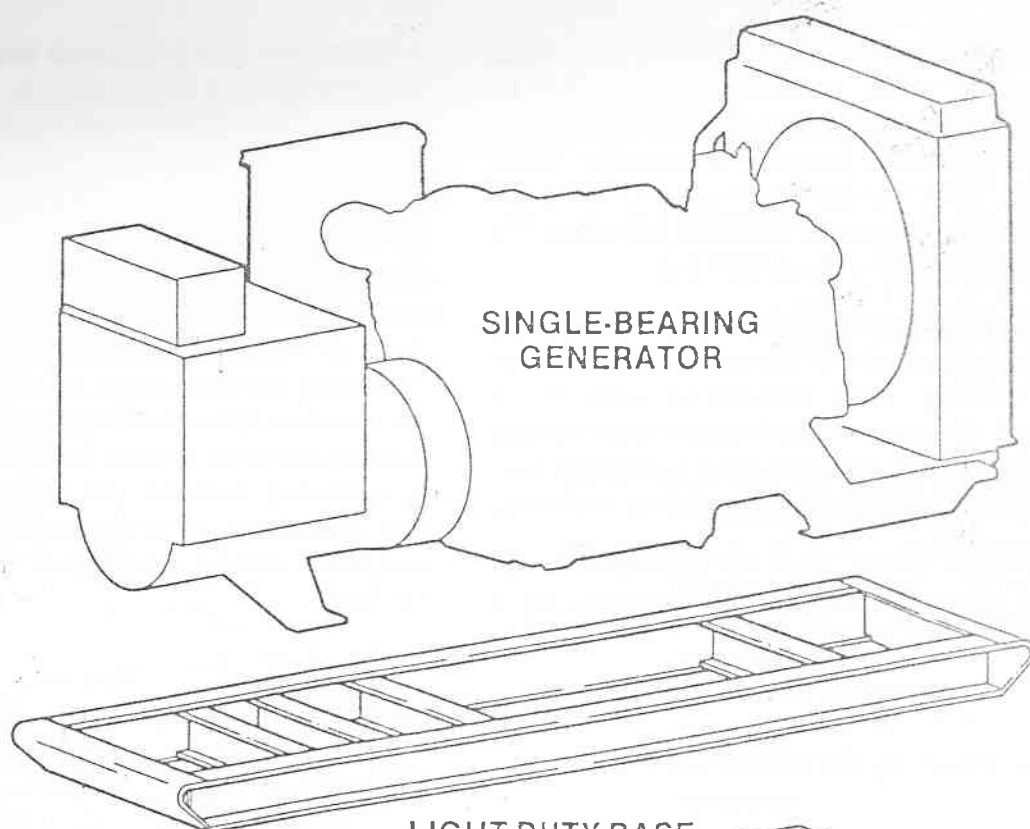


Figure 56 *

For engines with close-coupled single-bearing generators or engine-driven remote radiator fans, alignment can be maintained by mounting rails or modest bases. Two-bearing generators require a very rigid-base Figure 56. On long trains of equipment, such as generators driven from either end of the engine, tandem generators, or tandem engines, a substantial boxed base is required with three-point suspension (Figure 56). The base must incorporate sufficient strength to:

- Resist outside bending forces imposed on the engine block, couplings, and generator frame during transportation.
- Limit torsional and bending movement caused by torque reactions and maintain original factory alignment.
- Prevent resonant vibration in the operating speed range.

Due to the coefficient of thermal expansion

(cast iron $5.5 \times 10^{-6} \frac{\text{inches}}{\text{inch}}$ per °F); ($5.5 \times$

$106 \frac{\text{mm}}{\text{mm}}$ per 1.8°C), engines may expand

0.09 in (2.3 mm) in length from a cold start to operating temperature. **THIS GROWTH MUST NOT BE RESTRAINED.** On single-bearing and most two-bearing generators

no close clearance dowels or ground body bolts should be used which would limit the engine's thermal growth. On those rare instances with two-bearing generators when extremely close alignment is required, a ground body bolt can be used at the fly-wheel end on one side of the engine. No other restraint is permitted for the engine.

The mounting feet of a two-bearing generator can be doweled without causing harm. Slight expansion within the generator can be absorbed within the generator coupling.

VIBRATION

Any mechanical system which possesses mass and elasticity is capable of relative motion. If this motion repeats itself after a given time period, it is known as vibration. An engine produces many vibrations as it operates due to combustion forces, torque reactions, structural mass and stiffness combinations, and manufacturing tolerances on rotating components. These unbalanced forces can create a wide range of undesirable conditions, ranging from unwanted noise to high stress levels and ultimate failure of engine or generator components.

Vibrating stresses reach destructive levels at engine speeds which cause resonance. Resonance occurs when the natural frequency of the system coincides with the frequency of the vibrations. The total engine-generator system must be designed to avoid critical linear or torsional vibrations.

VIBRATION SEVERITY CHART

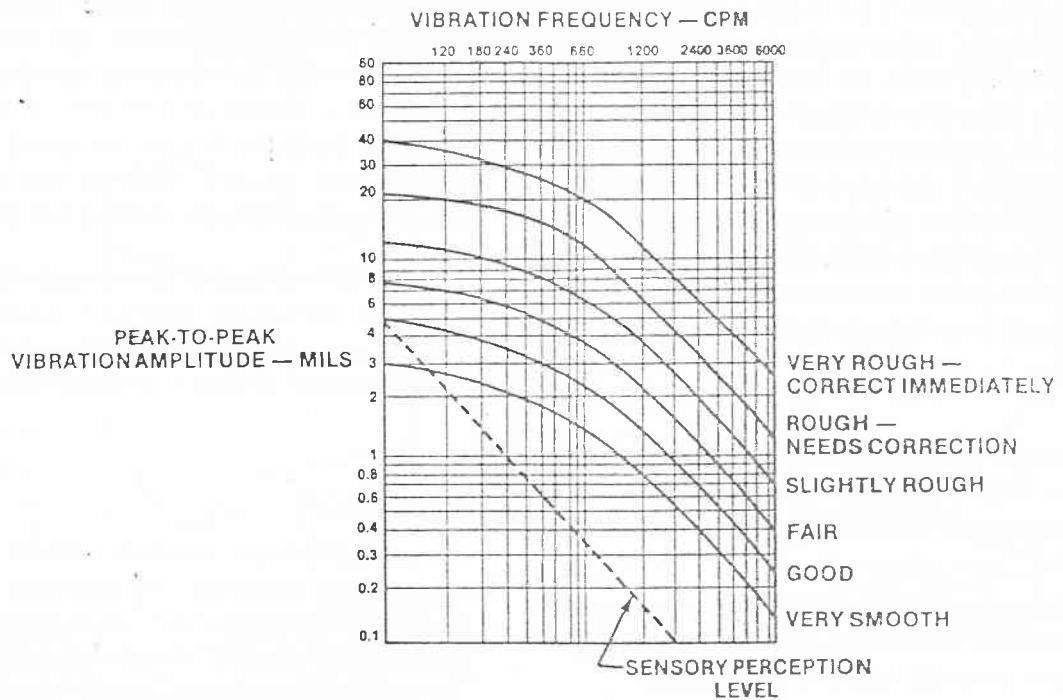


Figure 57

Linear Vibration

Linear vibration is usually identified by a noisy or shaking machine. Its exact nature is difficult to define without instrumentation. The human senses are not adequate to detect relationships between the magnitude of displacement of a vibration and its period of occurrence. For instance, a first order ($1 \times \text{rpm}$) vibration of 0.010 in (0.254 mm) displacement may feel about the same as third order measurement of 0.002 in (0.051 mm).

However, as depicted in Figure 57, the severity of vibration does correlate reasonably well with levels of perception and annoyance.

Vibration occurs as a mass is deflected and returned along the same plane, and can be illustrated as a single mass spring system Figure 58.

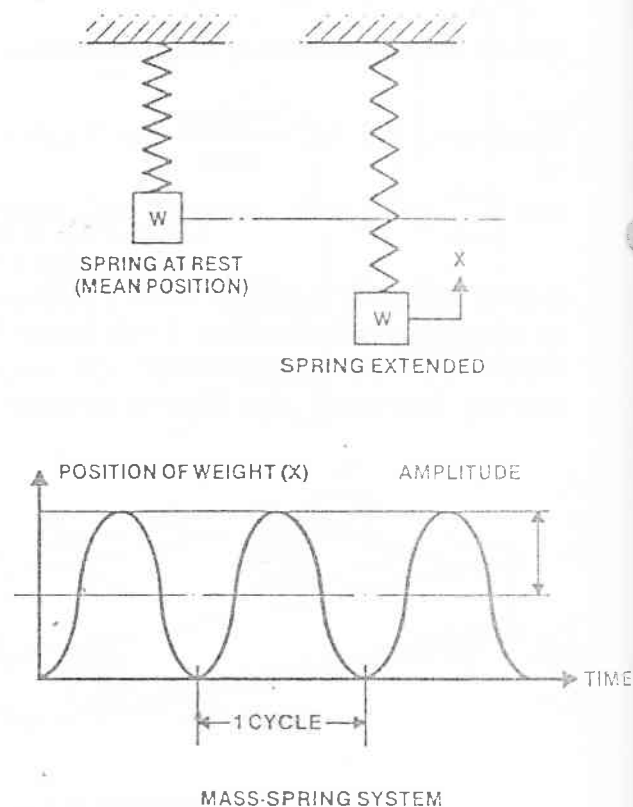


Figure 58

As long as no external force is imposed on the system, the weight remains at rest and there is no vibration. But, when the weight is moved or displaced and then released, vibration occurs. The weight will continue to travel up and down through its original position until frictional forces again cause it to rest. When a specific external force, such as engine combustion, continues to affect the system while it is vibrating, it is termed "forced vibration."

The period of time required for the weight to complete one complete movement is simply called a period.

The maximum displacement from the mean position is referred to as the amplitude: time interval in which the motion is repeated is called the cycle.

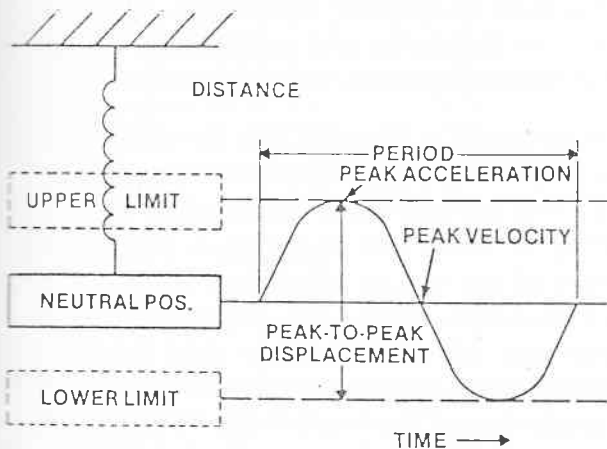


Figure 59

If the weight needs one second to complete a full cycle, the vibration frequency of this system would be one cycle per second.

If one minute, hour, day, etc., were required, its frequency would be one cycle per minute, hour, day, etc. A system that completed its full motion 20 times in one minute would have a frequency of 20 cycles per minute or 20 cpm.

Establishing the vibration frequency is necessary when analyzing the type of problem. It allows identification of the engine component or mass system which is causing the vibration.

The total distance traveled by the weight, that is from one peak to the opposite peak, is referred to as the peak-to-peak displacement.

This measurement is usually expressed in mils, where one mil equals one-thousandth of an inch (0.001 in). It can be used as a guide in judging vibration severity.

Both average or root-mean-square (rms) is sometimes used to measure vibration. $Rms = 0.707$ times the peak of vibration. These readings are referred to in theoretical discussions.

Another popular method used to determine the magnitude of vibration is to measure the vibration velocity. Note that the example is not only moving, but also changing direction. This means that the speed of the weight is also constantly changing. At its limit of motion, the speed of the weight is "0." As it passes through the neutral position its speed or velocity is greatest.

The velocity is an extremely important characteristic of vibration but, because of its changing nature, a single point has been chosen for measurement. This is the peak velocity and is normally expressed in inches per second peak.

Velocity is a direct measure of vibration and, as such, provides the best overall indicator of machinery condition. It does not, however, reflect the effect of vibration on brittle material.

The relationship between peak velocity and peak-to-peak displacement can be found by the following formula:

$$V \text{ Peak} = 52.3 D F \times 10^{-6}$$

Where: V Peak = Vibration velocity in inches per second peak.

D = Peak-to-peak displacement, in mils (1 mil = 0.001 in).

F = Frequency in cycles per minute (cpm).

Vibration acceleration is another important characteristic of vibration. It is the rate of change of velocity. In the example, note that peak acceleration is at the extreme limit of travel where velocity is "0." As the velocity increases, the acceleration decreases until it reaches "0" at the neutral point.

Acceleration is normally referred to in units of "g" (peak), where "g" equals the force of gravity at the earth's surface. ($980 \times 665 \text{ cm/s}^2 = 386 \text{ in/s}^2 = 32.2 \text{ ft/s}^2$)

Acceleration measurements or "gs" are commonly used where relatively large forces are applied. At very high frequencies (60,000 cpm) it is perhaps the best indicator of vibration.

The vibration acceleration can be calculated as:

$$g \text{ Peak} = 1.42 D F^2 \times 10^{-8}$$

Most machinery vibration is complex and consists of many frequencies. Displacement, velocity, and acceleration are all used to diagnose particular problems. Displacement measurements tend to be a better indication of vibration under conditions of dynamic stress and are, therefore, most commonly used. Note that the overall or total peak-to-peak displacement described in Figure 60 is approximately the sum of all the individual vibrations.

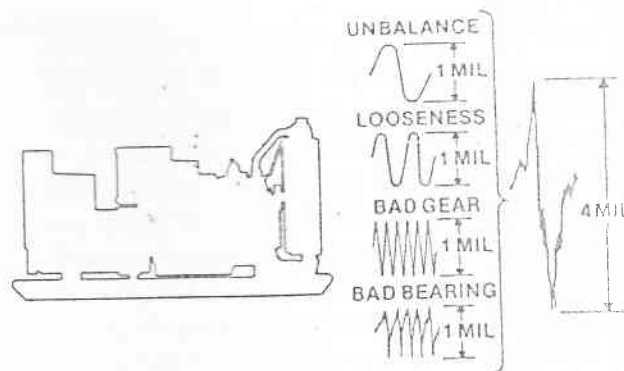


Figure 60

Isolation

Generator sets are capable of withstanding all self-induced vibrations and no isolation is required merely to prolong their service life. However, vibrations from surrounding equipment, if severe, can harm a generator set which is inoperative for long periods of time. Bearings and shafts can beat out and ultimately fail if these vibrations are not isolated. A running generator set will rarely be harmed by exterior vibrations. The method of isolating the unit is the same for exterior vibrations as it is for self-induced ones.

If no isolation is required, the generator set may be placed directly on the mounting surface. This surface must be capable of supporting at least 25% more than the static weight of the unit to withstand torque and vibratory loads. Unless the engine is driving equipment which imposes a side load, no anchor bolting is required. This will normally apply to all generator set mountings. Thin rubber or composition pads are suggested to minimize the unit's tendency to creep or fret the surface of the foundation.

Vibration can be dampened by two basic methods: commercially available fabricated isolators or bulk isolators. Both of these techniques utilize static deflection to isolate, with increased deflection resulting in greater isolation. Although the internal damping of various materials will cause some difference in performance, the vibra-

tion chart in Figure 61 describes the general effect deflection has on isolation. By using engine rpm as the nominal vibration frequency, the magnitude of compression in an isolating material can be estimated for precision calculations. The properties of the specified material must be analyzed.

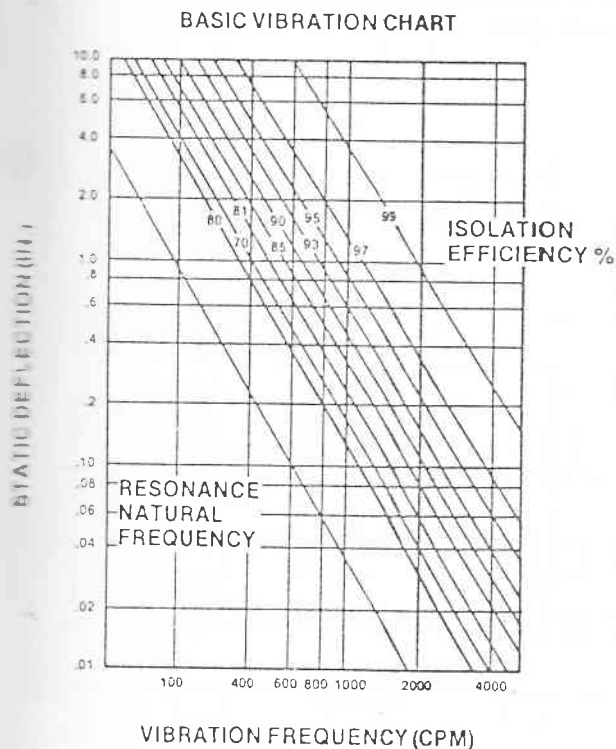


Figure 61

The unit can be separated from the supporting surfaces by these "soft" commercial devices, i.e., those which will deflect under the static weight. The mounting rails or fabricated base must withstand all torque reactions without benefit of uniform support from the isolators.

All piping connected to the generator set may require isolation. Fuel and water lines, exhaust pipes, and conduit could otherwise transmit vibrations long distances. Isolator pipe hangers, if used, should have springs to attenuate the low frequencies, and rub-

ber or cork to minimize transmission of high frequencies. To prevent the buildup of resonant pipe vibrations, long piping runs should be supported at unequal distances Figure 62.

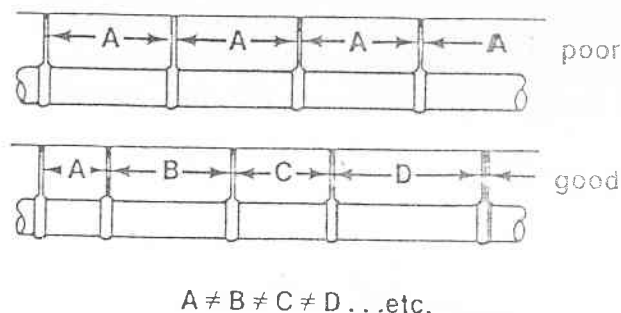


Figure 62

Isolation For Mobile Equipment

Isolation from a movable platform is desirable to:

1. Reduce vibration.
2. Reduce noise.
3. Prevent flexing of the platform or trailer bed from being transmitted to the generator set.

Vibration can be carried throughout an enclosure and cause early failure of auxiliary equipment. Relays, switches, gauges, and piping are adversely affected.

Noise, while normally only an annoyance, can reach levels which are objectionable to owners and operators alike. If operating near property lines, the noise could exceed local ordinances.

Perhaps the most important reason to isolate mobile equipment is to avoid bending of the generator set by movement of the subbase. Unless the platform or trailer bed is extremely rigid, the generator set must not be bolted to it. Deflection of the bed would be transmitted to the engine, causing block bending and possible crankshaft and bearing failures.

Lateral movement of the generator set must be minimized as the trailer is transported. This can be achieved simply by lifting the unit off the isolators during the move. If this is not practical, snubbers can be used to confine vertical and horizontal movement.

A detail of a spring-type isolator Figure 63 shows the addition of thrust blocks to restrict lateral movement without interfering with the spring function of the unit.

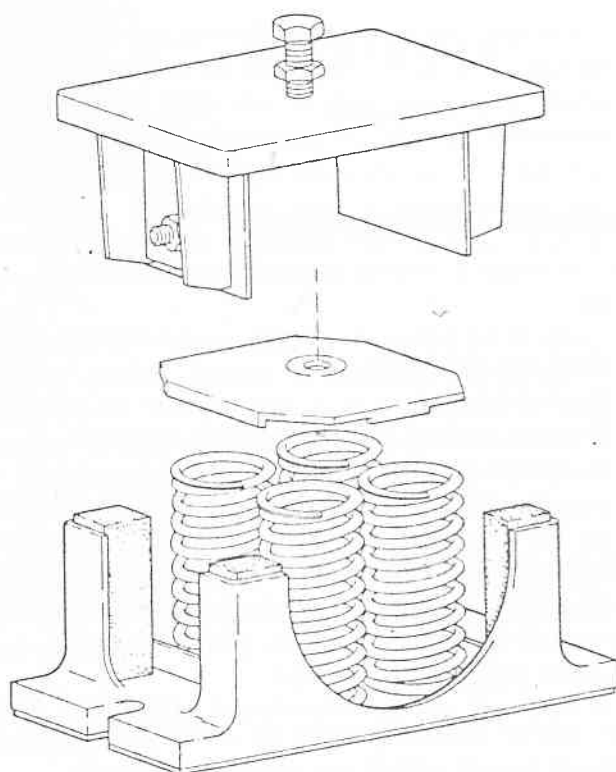


Figure 63

Commercial Isolators

Several commercial isolators are available which will provide varying degrees of isolation. Care must be taken to select the best isolator for the application. Generally, the lower the natural frequency of the isolator (soft), the greater the deflection and the

more effective the isolation. However, the loading of the isolator must not be exceeded.

The weight of the generator set can be unequally balanced on the isolators, depending on where they are located. Generally, isolators are most effective when located under the mounting foot of the generator and the front support of the engine Figure 64. If additional support is desired, it is customary to place an isolator midway between the front and rear one.

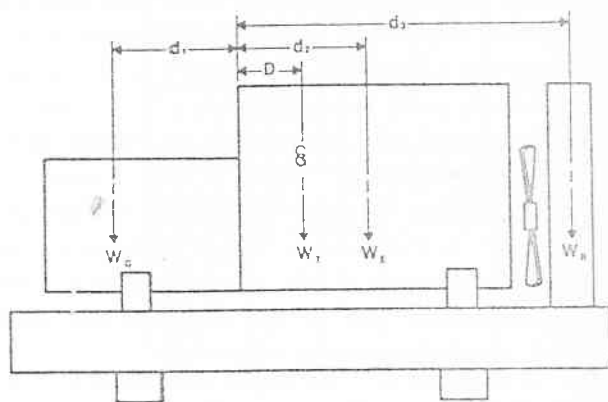


Figure 64

The total wet weight and the center of gravity of the assembled unit must first be established. Assuming an engine and generator are assembled to a base, the total wet weight (W_T) and assembled center of gravity (\bar{g}) can be calculated. A common reference point is needed. In this case, use the rear face of the flywheel housing. Because measurements are to both sides of the reference, one direction can be considered negative. Therefore:

$$W_T(D) = W_G(-d_1) + W_E(d_2) + W_R(d_3)$$

$$D = \frac{W_E(d_2) - W_G(d_1) + W_R(d_3)}{W_T}$$

If additional equipment is added, such as a radiator, the process is repeated to determine a new center of gravity.

Having established the center of gravity for the total unit, the loading on each isolator can be determined by:

$$S_1 = W_1 \left(\frac{a}{c} \right)$$

$$S_2 = W_1 \left(\frac{b}{c} \right)$$

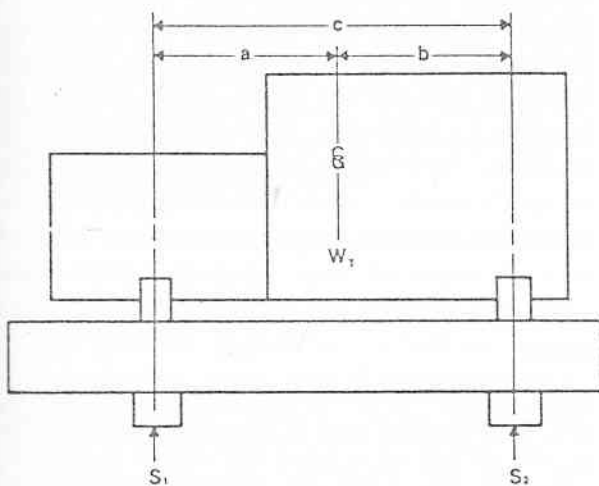


Figure 65

No matter what type of isolation is used, it should be sized to have its natural frequency as far removed from the exciting frequencies of the engine as possible. If these two frequencies were similar, the entire unit would be in resonance. The transmissibility chart in Figure 66 depicts this condition. It also shows the significant improvement caused by decreasing the mounting natural frequency to allow a ratio increase above $\sqrt{2}$ (1.42).

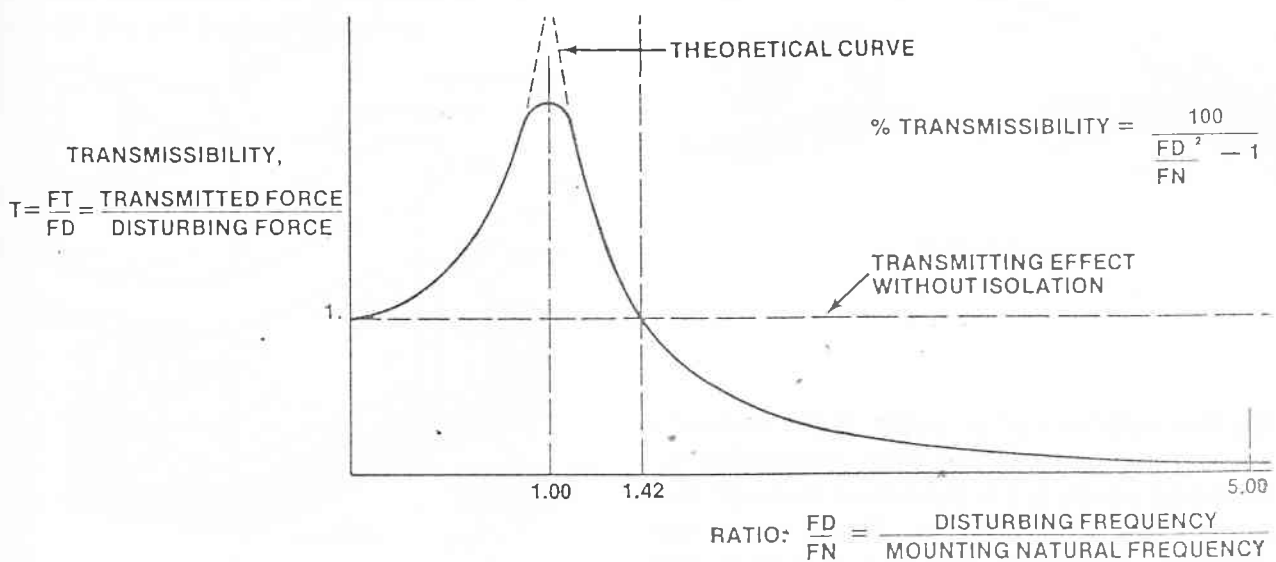


Figure 66

The most effective isolators are of the steel spring design. They are capable of isolating 96% of all vibrations, provide overall economy, and permit mounting the generator set on a surface which need only be capable of supporting the static load. No allowance for torque or vibratory loads are required. As with nonisolated mountings, no anchor bolting is usually required. However, if operating in parallel with other units, the extreme torques, which may occur because of an out-of-phase condition, require the isolators to be firmly fastened to the foundation. The spring isolators also are available with rubber side thrust isolation for use when the engine is side-loaded or located on a moving surface.

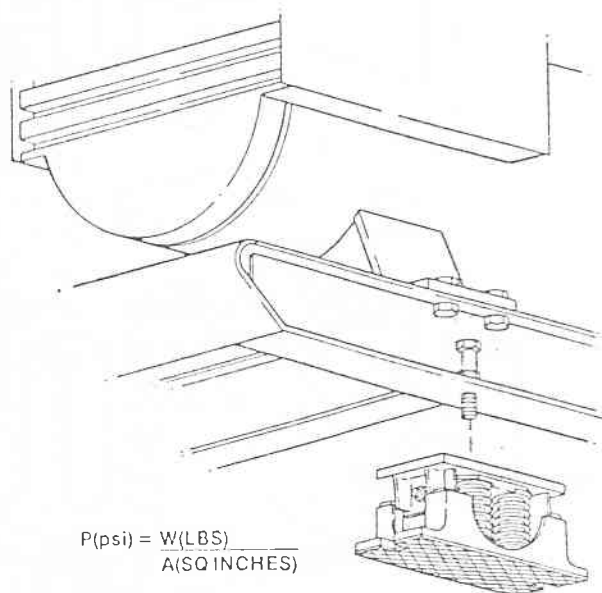


Figure 67

By the addition of a rubber plate beneath the spring isolator, the high frequency vibrations which are transmitted through the spring are also blocked. These high frequency vibrations are not harmful but cause annoying noise.

Rubber-type isolators are adequate for applications where vibration control is not severe. By careful selection, isolation of 90% is possible. They will isolate most noise created by transmission of vibratory forces. But, care must be exercised to avoid using rubber isolators which have the same natural frequency as the engine exciting frequencies in both the vertical and horizontal planes.

Fiberglass, felt, composition and flat rubber of a waffle design do little to isolate major vibration forces, but do isolate much of the high frequency noise. The fabric materials tend to compress with age and become ineffective. Because deflection of these types of isolators is small, their natural frequency is relatively high compared to the engines. Attempting to stack these isolators or apply them indiscriminantly could force the total system into resonance.

Bulk

Bulk isolating materials are used between the foundation and supporting surface but are not as foolproof as the spring- or rubber-types.

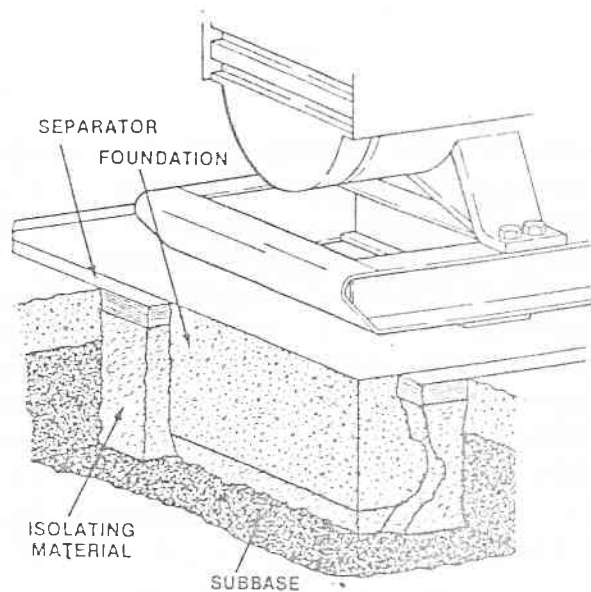


Figure 68

Isolation of block foundations may also be accomplished by using eight to ten inches of wet gravel or sand in the bed of the foundation pit. Sand and gravel are capable of reducing the amount of engine vibration transmitted by as much as one-third to one-half. The isolating value of gravel is somewhat greater than that of sand. To minimize settling of the foundation, the gravel or sand should be thoroughly tamped before pouring the concrete block. The foundation pit should be made slightly longer and wider than the foundation block base. A wooden form the size and shape of the foundation is then placed on the gravel or sand bed for pouring the concrete. After the wooden form is removed the isolating material is placed around the foundation sides, completely isolating the foundation from the surrounding earth.

Rubber, asphalt-impregnated felt and fiber glass have also been used for isolating the foundation block from the subsoil, but they do not provide significant vibration isolation, isolating only those high-frequency vibrations which cause noise. Whatever method is used, the floor slab surrounding the foundation block should always be separated from the foundation by expansive joint material. This prohibits the vibration from traveling from the block to the floor and also eliminates the possibility of losing tools in the pit during servicing.

Cork is normally not effective with operating frequencies below 1800 cps and, if not kept dry, will rot. For these reasons it is seldom used with modern generator sets. It can be used as a separator between the unit foundation and surrounding floor due to its resistance to oils, acids, or temperatures between 0°F (-18°C) and 200°F (93°C).

Seismic

Seismic shocks are not considered sufficient to harm a generator set if the unit is resting on the floor or ground. However, isolation equipment, particularly spring isolators, could amplify the relatively small forces generated by an earthquake to a level which would damage the generator set or switchgear. Special isolators which incorporate seismic restraining or damping devices are available, but exact requirements must be reviewed by the supplier of the equipment. Isolators anticipating seismic shock must be bolted to the equipment base and to the floor. Positive stops should be added to limit motion of the isolators in all directions. Attached piping and auxiliary equipment supports must also be reviewed to assure the relative movement can be tolerated.

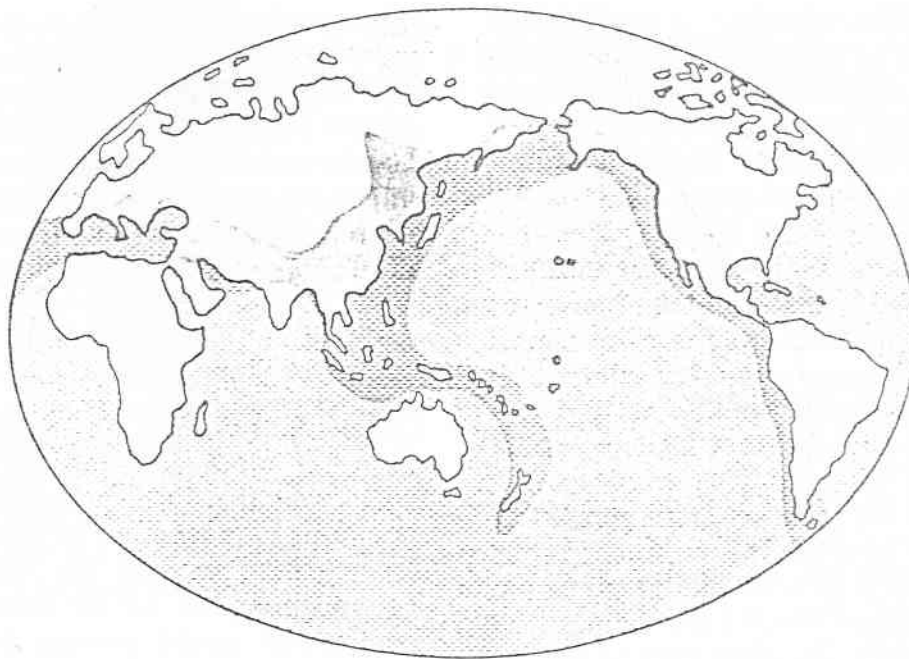
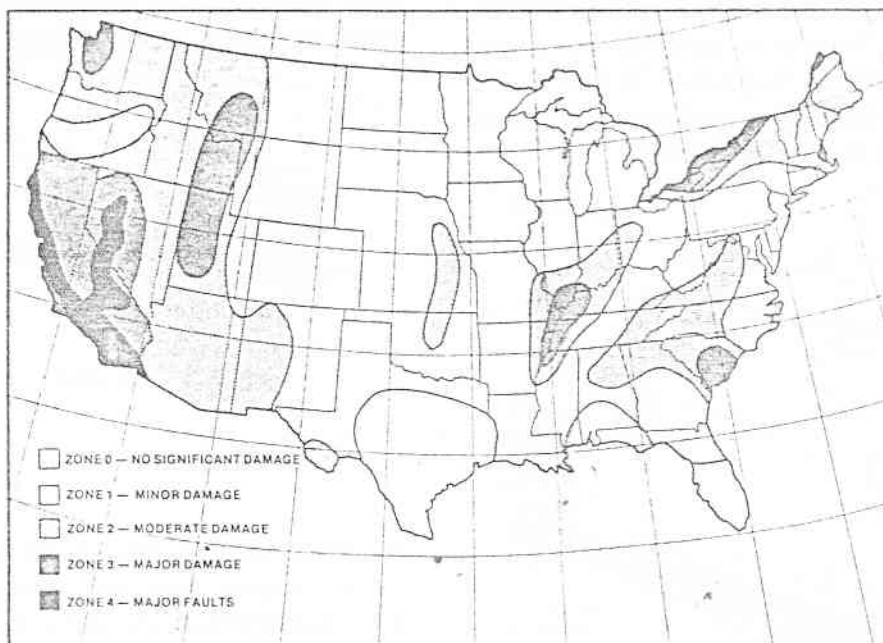


Figure 69

Figure 69 describes the seismic activity which has occurred throughout the world since 1897.

The United States has been further divided into regions of earthquake damage probability Figure 70.



SEISMIC ZONE MAP OF THE UNITED STATES

Figure 70

Torsional

Torsional vibration occurs as an object, such as an engine crankshaft, twists and returns. Standard generator set components are designed to withstand the normal stresses caused by combustion forces and torque reactions. A generator set must be designed to prevent the natural frequency of the drive train from being similar to the unit's operating speed. Failure of crankshaft, couplings, gears, or bearings may result without this attention.

Torsional vibrations originate with the power stroke of the piston. The simplified drivetrain in Figure 71 illustrates the relationship of shaft diameter, length, and inertia on the natural frequency of the system.

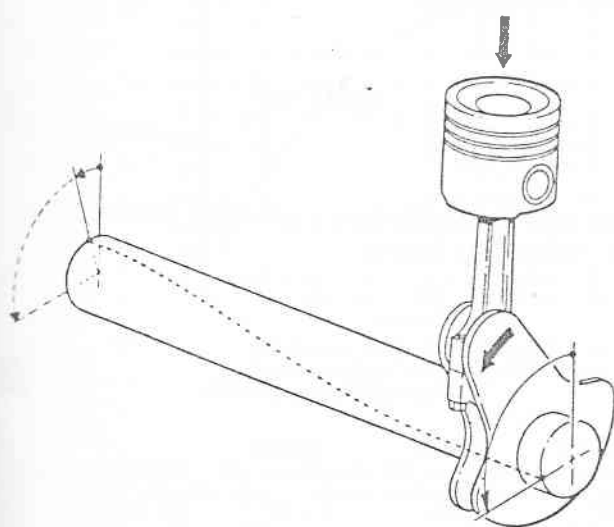


Figure 71

Generator sets, which are prepackaged by the factory, are designed to avoid critical speeds where resonant conditions would occur. On applications which require that the engine and a single-bearing generator be matched in the field or that include aux-

iliary equipment driven from the front of the engine, a torsional analysis must be made. This assures that the engine and generator are compatible. The analysis can usually be completed by the engine supplier.

If a two-bearing generator is specified, a torsionally resilient (soft) coupling is included between the engine and generator. A torsional study by the engine supplier is again recommended.

The torsional study will accurately predict the operating characteristics of the generator set's mass elastic system. This system is the combination of masses (or inertias) and springs that constitute the vibrating system. When considering torsional vibrations, the mass elastic system considers the pistons, rods, crankshaft, flywheel, coupling, driven equipment and any associated shafting. Good results from an analysis require accurate input concerning:

A. Engine

1. High idle speed.
2. Low idle speed.
3. Governed speed.

B. Driven equipment

1. General arrangement drawing or sketch of complete system, with all significant dimensions, including data on special crankshaft pulley and equipment driven from front of engine.
2. WR^2 and torsional rigidity in pound-inches per radian of deflection on all couplings used between the engine and driven equipment.
3. WR^2 and principal dimensions of each rotating mass. Weight and principal dimensions of each reciprocating mass.
4. WR^2 and principal dimensions of all connecting shafts.

Cyclic Irregularity

Cyclic irregularity is a nondimensional ratio and refers to the degree of twist which occurs in a crankshaft between two successive firings of cylinders during steady state operation. Many formulae to represent this movement were derived before modern instrumentation allowed actual measurement. The ratio is expressed as:

$$\text{Cyclic Irregularity} = \frac{\text{rpm (max)} - \text{rpm (min)}}{\text{rpm (avg)}}$$

The system speed will vary depending on the connected rotating mass. The cyclic irregularity will, therefore, be different for a basic engine, a generator set, a different generator, or with additional driven equipment.

This ratio was used to compare the merits of large slow-speed engines which were custom made but has little value when applied to modern medium-speed engines.

When necessary to satisfy equipment specifications, this ratio can be obtained from the Caterpillar Dealer.

NOISE

Noise can be defined as unwanted sound, and there is an increasing need to define and control this noise.

Exposure to excessive noise levels may cause permanent hearing damage, and adversely affect working efficiency and comfort. Recognizing this, the U.S. Government created the Occupational Safety and Health Act, which established noise limits for industrial environments.

When an employee's daily noise dose — designated D(8) — is composed of two or more periods of noise at different levels, the combined effect is calculated using this formula: $D(8) = (C_1/T_1) + (C_2/T_2) + \dots + (C_n/T_n)$, where C_n is the duration of exposure at a specified sound level and T_n is the total time of exposure permitted at a specified sound level from Figure 72. The noise dose is considered to be acceptable when the daily dose is equal to or less than 1.

Duration of Daily Exposure Hours	Allowable Level dB (A) *
8	90
6	92
4	95
3	97
2	100
1-1/2	102
1	105
1/2	110
1/4 or less	115

Figure 72

This can be related to common sounds by the following chart:

Typical Noise Levels

Sound Power, w	Sound Pressure, dB	Sound Pressure, psi	Common Sounds
10^4	160	3×10^{-1}	Jet Engine
10^2	140	3×10^{-2}	Riveting
1	120	3×10^{-3}	Punch Press
10^{-2}	100	3×10^{-4}	City Traffic
10^{-4}	80	3×10^{-5}	Busy Office
10^{-6}	60	3×10^{-6}	Normal Speech
10^{-8}	40	3×10^{-7}	Quiet Suburb
10^{-10}	20	3×10^{-8}	Whisper
10^{-12}	0	3×10^{-9}	Threshold of Hearing

Figure 73

Note that Figure 73 relates sound pressure in decibels (dB) and pounds per square inch (psi). However, to measure the loudness of sound, the frequency of the noise must be considered. The sound measurements weighted to the human ear are referred to as the A scale. Figure 74 indicates the degree that the "A" scale will fall below an unfiltered measurement. Because it reflects the real impact on the human ear, the dB(A) scale has been accepted worldwide.

For noises of practical interest, the differences in sound power levels are not large. Knowing that doubling the sound pressure will result in only a 6 dB increase is also helpful.

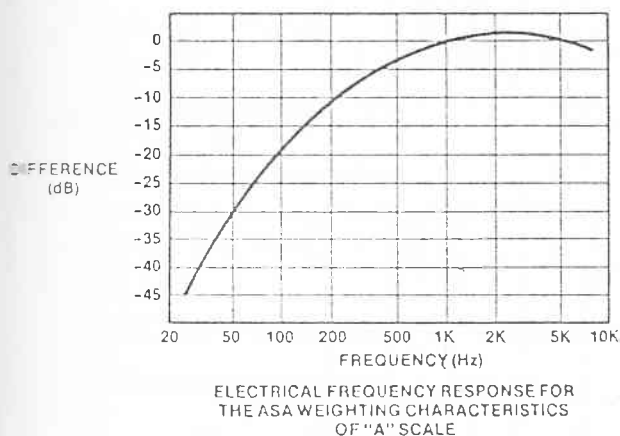


Figure 74

The following charts will aid in predicting overall engine room noise. These levels are

anechoic (free) field measurements which do not account for the effect of surrounding machines, floor, walls, etc. The effect of distance on sound is straightforward. Doubling the distance will decrease the sound 6 dB; halving the distance from the source will increase the measurement by 6 dB.

Control

Exhaust noise attenuation is commonly achieved by the use of a quality muffler. Because the number of cylinders and speed of various engines create varied exhaust generation frequencies, the specific effect of a muffler must be predicted by the muffler manufacturer. The standard Caterpillar silencer will typically reduce the exhaust noise about 15 dB(A) when measured 10 ft (3.3 m) perpendicular to the exhaust outlet.

Many of the techniques used to isolate generator set vibrations can also be applied to mechanical noise isolation. Modest reductions of noise can be accomplished by attention to the noise source, i.e., reduce fan speeds, coating of casting areas, ducting of air flows. But for attenuation greater than 10 dB(A), the total unit should be totally isolated. One effective method utilizes concrete blocks filled with sand to completely house the generator set. In addition, the unit must incorporate vibration isolation techniques described in the Vibration Section to prevent the transmission of noise. A rough guide in comparing various isolation methods is illustrated in Figure 77.

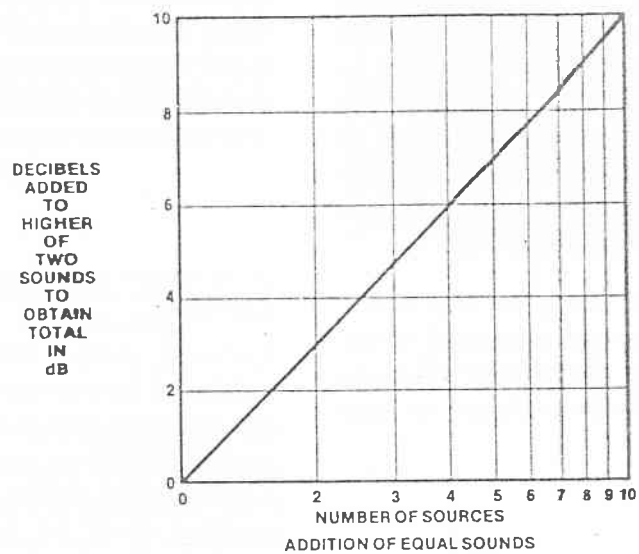


Figure 75

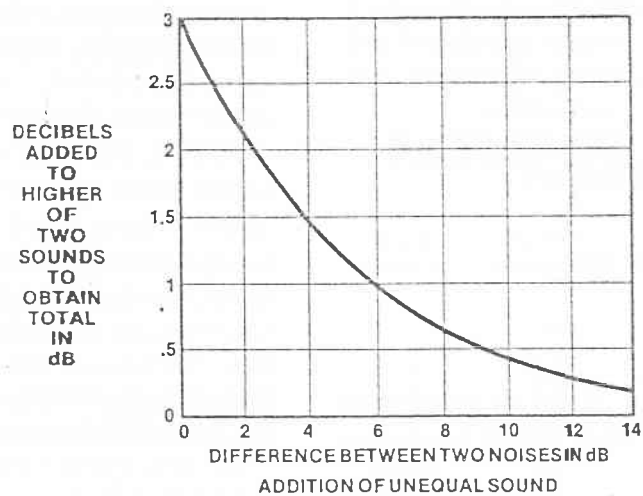


Figure 76

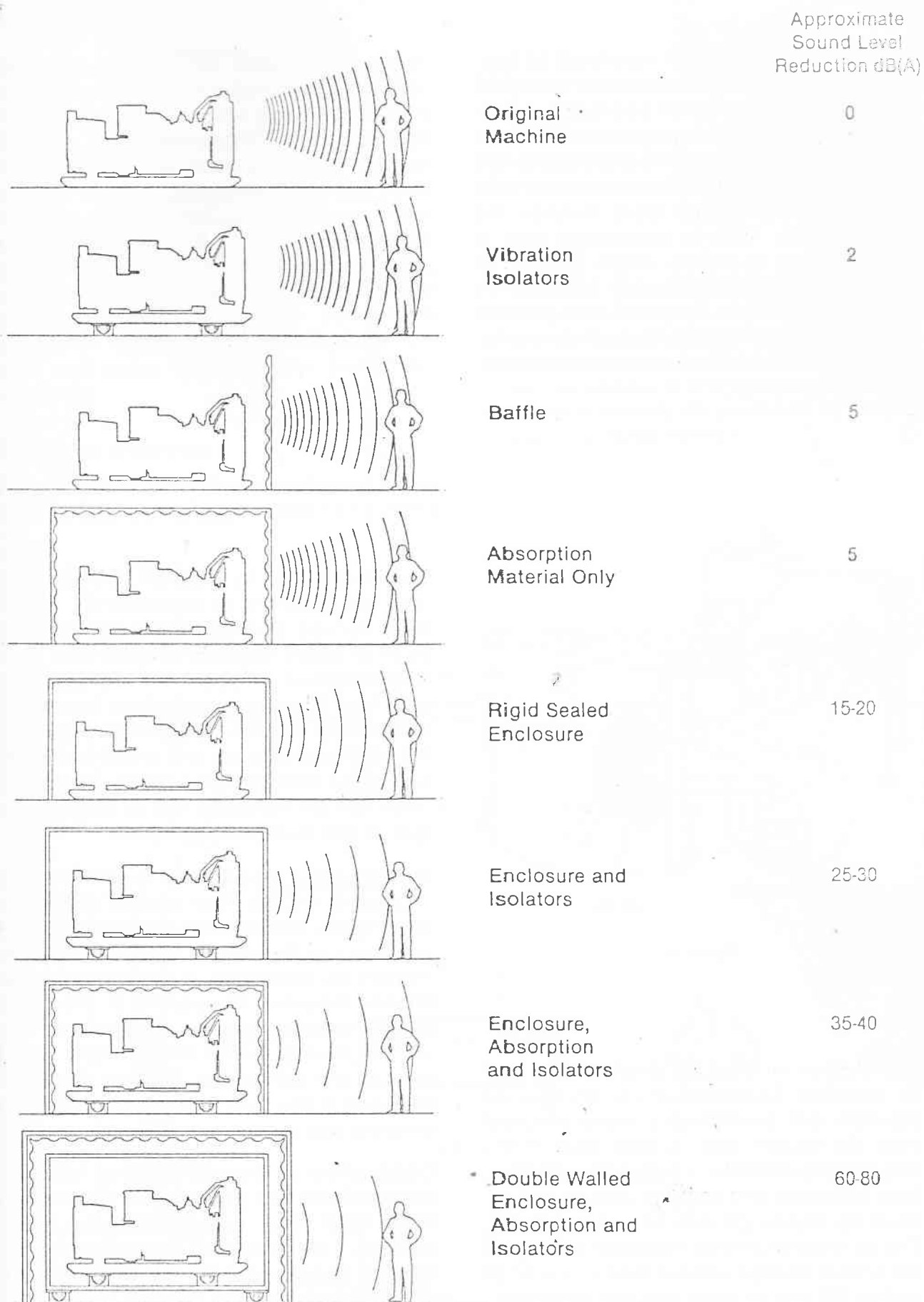


Figure 77

AIR INTAKE

A diesel engine requires approximately 2.5 cfm (0.07 m³/min) of air per brake horsepower produced. Normally this air can be obtained from the air surrounding the engine but, in some circumstances, combustion air is ducted from outside the engine room. This is particularly true in high altitude operation where normal air densities can be adversely affected by warm engine room temperatures. Another section of this manual discusses the effects of altitude and temperature on generator set operation.

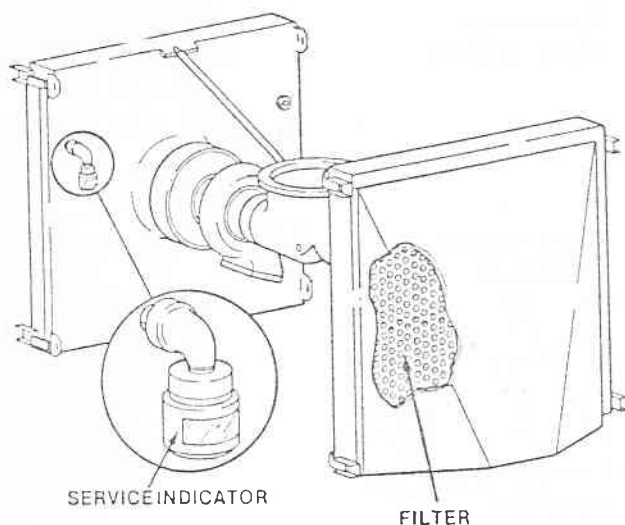


Figure 78

Combustion air must be clean and as cool as possible. Engine-mounted, dry-type air cleaners are considerably more efficient than the oil-bath-type. A new filter offers very little restriction so that total air restriction, including any ducting, should not exceed 10 inches (25 cm) of water column. The air cleaner service indicator will signal for a filter change when a restriction of 30 inches (76 cm) of water column develops.

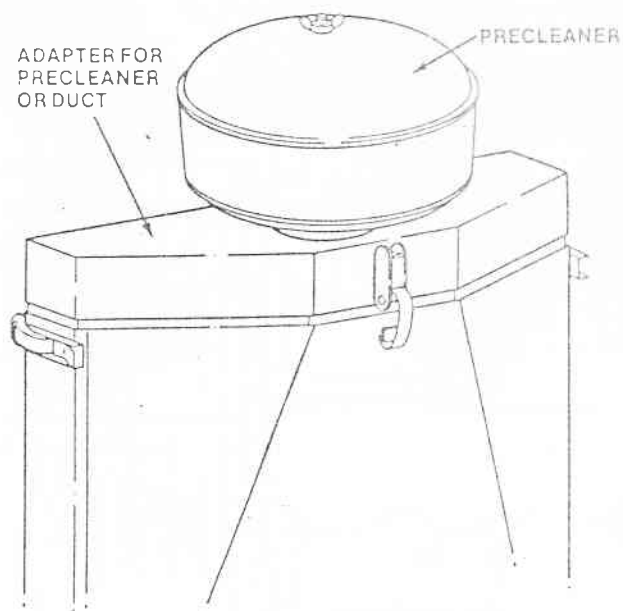


Figure 79

Precleaners can be adapted to most standard air cleaners to significantly extend filter service periods Figure 79. They impose an added restriction on the filter of 1-3 in (2.5-8 cm) of water, but will increase standard filter life about three times. Heavy-duty air cleaners provide the same protection as the standard filter but will allow further extension of filter change periods. Service periods can be increased six to seven times that of the standard air cleaner.

When ducting is necessary to assure cooler or cleaner air, the filter should remain on the engine. Harmful dirt leaking into ducting joints or the remote filter housing can thereby be eliminated. If the filter must be remote mounted, the piping at the turbo-charger must encourage a smooth air flow with at least a 2 in (5 cm) straight length prior to the connection. Baffles should be included in the duct to prevent water from entering the engine.

Combustion air through ducting must not exceed 2,000 fpm (615 m/min) if excessive noise and flow restrictions are to be avoided. Total head loss (restriction) in the ducting should generally be less than 2 in (5 cm) of water column in order to maximize

the time between air filter replacement. The procedures to calculate ducting restrictions are contained in the Exhaust Systems Section. As a nominal guide, ducting with a diameter equal to the standard air cleaner adapter can accommodate 25 ft (7.6 m) of straight pipe. Increasing this diameter 1 in (2.5 cm) will allow 65 ft (19.8 m) of straight pipe. Pipe bends should be of long radii, with flanged or welded joints to encourage low restrictions. A flexible connection should be included to isolate engine vibration and noise and to allow easy filter servicing.

EXHAUST SYSTEMS

The purpose of an exhaust system is to collect exhaust gases from the engine cylinders

and to discharge them as quickly and silently as possible. A primary aim of the design should be to minimize the backpressure introduced, since restriction of the exhaust gas flow causes loss of horsepower and increased operating temperature.

Manifolds

The engine exhaust manifold collects exhaust gases from each of the cylinders and channels them into a single exhaust outlet. The manifold is designed to encourage minimum backpressure and turbulence. Several types of manifolds are available for varying installation requirements.

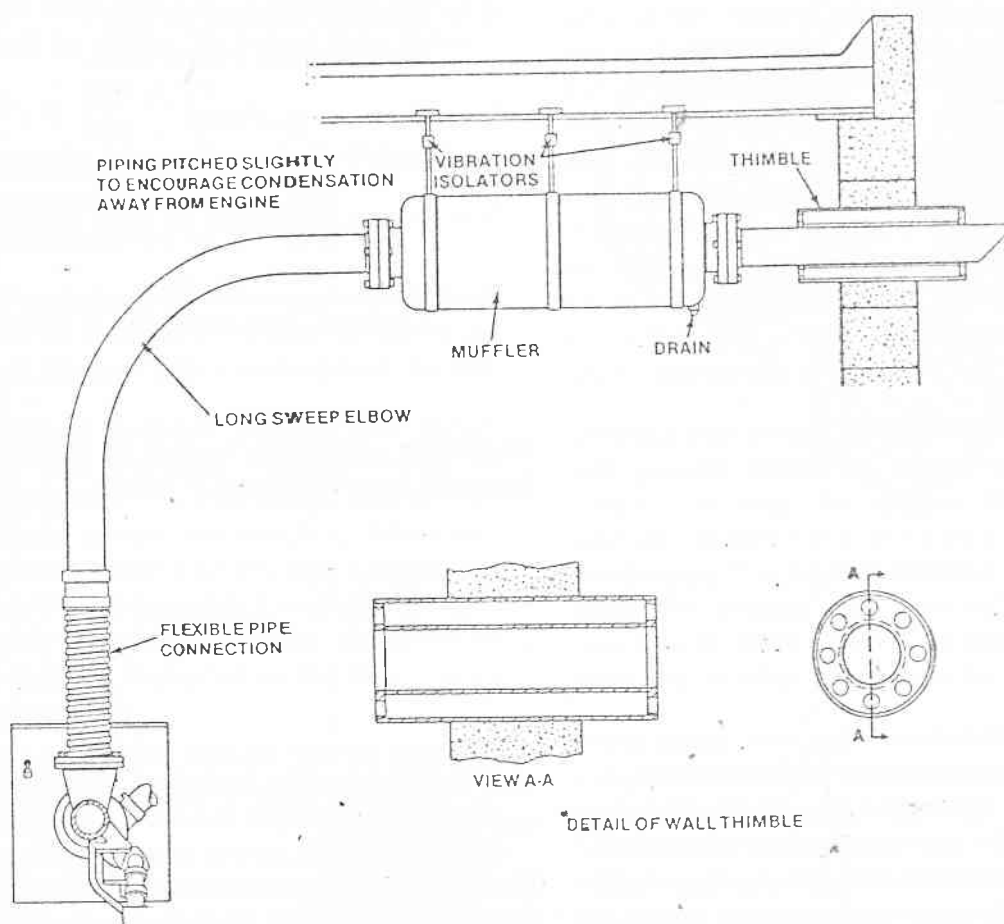


Figure 80

In place of the dry manifold which may be standard equipment, watercooled or water-shielded manifolds may be specified. Either manifold is used primarily to protect the operator from contact with the hot manifold, but is not particularly effective in reducing heat radiated to the engine room. The watercooled type is an integral assembly with passages to allow engine jacket coolant to flow through the manifold, thus conducting away some of the heat that would otherwise be carried by the exhaust gas. Heat rejection to the jacket water will increase about 15%, while loss of exhaust heat energy may cause engine deration and/or loss of altitude capability.

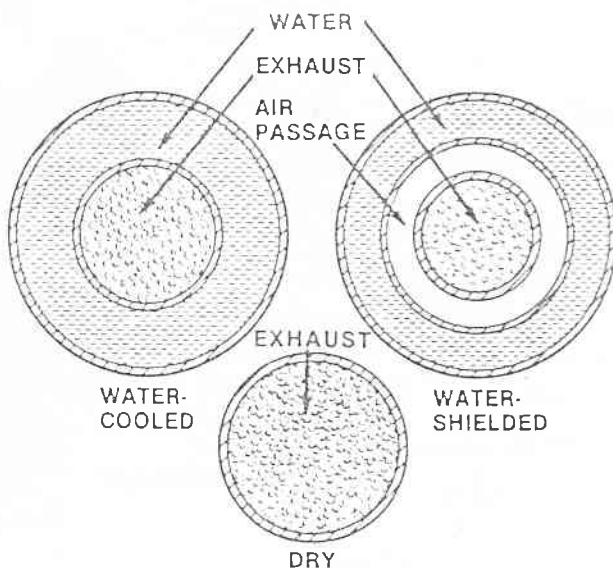


Figure 81

The water-shielded type is supplied with an auxiliary jacket or shield. Engine water circulates through the shield but does not come into direct contact with the manifold casting. It adds very little to the cooling load of the engine and will not affect engine performance.

Piping

The pressure drop across the exhaust system should generally not exceed 27 in (68 cm) of water. Each generator set should be reviewed to determine the maximum allowable backpressure and the exhaust gas volume at full load. Pressure losses due to piping, muffler and rain cap should be included when making the calculation.

The following formula may be used in calculating backpressure:

$$P = \frac{L \times S \times Q^2}{5184 \times D^5}$$

P = pressure drop (backpressure)
(pounds per square inch, psi)

L = length of pipe (feet)

S = specific weight of gas
(pounds per cubic foot)

Q = exhaust gas flow
(cubic feet per minute, cfm)

D = inside diameter of pipe (inches)

$$S = \frac{41.13}{\text{Exhaust Temperature} + 460^\circ\text{F}}$$

To obtain equivalent length of straight pipe for each long radius 90° bend:

$$L = \frac{15 \times D}{12}$$

The radius of 90° bends should be at least 1-1/2 times the pipe diameter to encourage low resistance.

The restrictions imposed by the standard Caterpillar muffler have been plotted on a curve which relates pressure drop to flow velocities Figure 82.

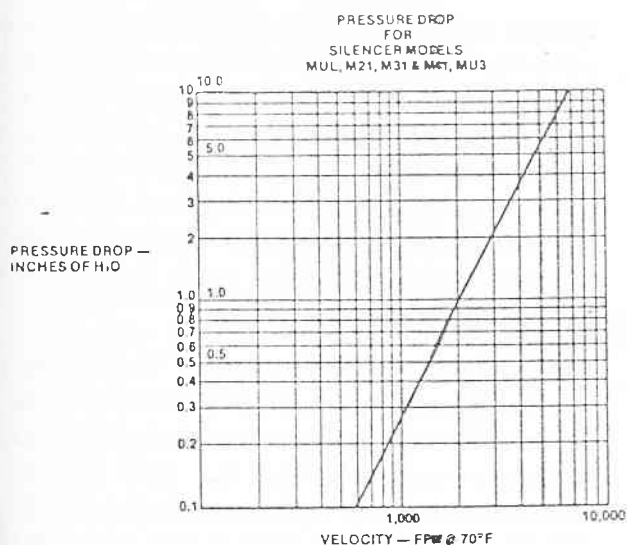


Figure 82

Because the velocity is plotted at 70° F, a correction from the actual exhaust temperature must be made. To adjust this value:

$$V_1 = V_2 \times \frac{460 + 70}{460 + T_2}$$

V_1 = Velocity at 70° F (fpm)

V_2 = Velocity of Exhaust Gas

T_2 = Temperature of Exhaust Gas

In those instances where pressure drop is measured in inches of water, dividing by 0.0361 will convert this measurement to psi.

Most exhaust system layouts are determined by the physical characteristics of the building and the equipment room. The arrangement which will result in minimum backpressure should be chosen, consistent with other requirements. The pipes should be securely supported; rubber dampers or springs may be included in the bracing to isolate vibrations.

Lines should be installed with at least 9 in (22.9 cm) clearance from combustible materials. Lagging exhaust pipes, which involves wrapping the pipe with a suitable, high-temperature insulation or installing prefabricated insulating sections over the pipe, will help to prevent radiation of heat in the

equipment room. Where the exhaust pipe passes through a wooden wall or roof, a metal thimble guard 12 in (30.5 cm) larger in diameter than the pipe should be installed.

The end of the exhaust pipe should be cut at 30° to 45° angle with the longitudinal axis to reduce turbulence at the outlet, thereby reducing the noise level. If the exhaust pipe is horizontal, bevel should slant back at the bottom to discourage the entrance of precipitation.

Vertical exhaust stacks should be of sufficient height that fumes and odors do not create a nuisance. A rain cap of the type which is forced open by exhaust pressure should be installed to keep water from entering the system.

Long horizontal and vertical exhaust systems should include a rain trap to allow moisture to drain from the pipes. The trap should be installed at the lowest point of the line as near as possible to the exhaust outlet so that water will not reach the silencer. The exhaust line from the engine and silencer should slope down slightly to the trap so that condensation will drain from the pipe. The trap may be built by inserting a tee section in the exhaust line. A short length of vertical pipe runs down from the tee, with a drain cock or removable plug at the lower end.

Correct placement of the exhaust muffler will greatly affect its silencing ability. By locating it near the engine, the transmission of sound to the exhaust piping will be minimized. The higher exhaust temperature near the engine will also reduce carbon buildup. A drain should be provided to relieve the muffler of any condensation.

Although it may seem economically tempting, a common exhaust system for multiple installations is usually not acceptable. Combined exhaust systems with boilers or other engines can allow operating engines to force exhaust gases into an engine which is not operating. The gas will condense an appreciable amount of water which

can cause engine damage. Additionally, soot can clog the turbocharger, aftercooler, or plug the air cleaner elements. The use of valves to separate the engine exhausts is also discouraged. The relatively high temperature can warp the valve, or soot deposits can cause leakage.

Exhaust draft fans have been applied successfully in combined exhaust ducts, but they must operate whenever any exhaust is introduced into the duct.

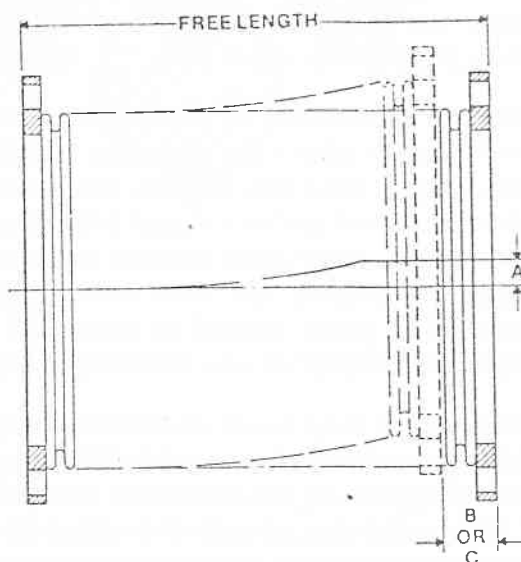
Flexible Connections

The exhaust pipe is usually isolated from the engine with flexible connections. They should be installed as close to the engine's exhaust outlet as possible. A flexible exhaust connection has three primary functions: (1) to isolate the weight of the exhaust piping from the engine. No more than 60 lb (28 kg) of exhaust piping weight should be supported by the engine; (2) to relieve exhaust components of excessive vibrational fatigue stresses; and (3) to allow for

relative shifting of the engine exhaust components. This shifting has numerous causes. It may result from expansion and contraction of components due to temperature changes, by slow but continual creep processes that take place throughout the life of any structure, or because of torque reactions when the generator set is mounted on spring-type isolators.

The growth and shrinkage of the exhaust pipe must be planned, otherwise it will create excessive loads on exhaust piping and supporting structure. From its cold state, a steel exhaust pipe will expand about 0.0076 in./ft of pipe for each 100° F rise of exhaust temperature (0.11 mm•m for each 100° C). This amounts to about a 0.65-inch expansion for each 10 feet of pipe from 100° F to 950° F (52 mm•m from 35° C to 510° C).

Long runs of exhaust pipe should be divided into sections having expansion joints between them. Each section should be fixed at one end and be allowed to expand at the other.



A. MAX. OFFSET BETWEEN FLANGES		B. MAX. COMPRESSION FROM FREE LENGTH		C. MAX. EXTENSION FROM FREE LENGTH	
in.	(mm)	in.	(mm)	in.	(mm)
0	0	1.50	38.1	1.00	25.4
.12	3.05	.90	22.86	.50	12.7
.25	6.35	.60	15.24	.28	7.11
.38	9.65	.40	10.16	.20	5.08
.50	12.7	.23	5.84	.00	.00
.75	19.05	.00	0.0	.00	.00

SPRING RATE OF BELLOWS = 170 LBS/INCH (19.21 N/m) APPROX.

IF BELLOWS-TYPE EXHAUST FITTINGS ARE DISTORTED BEYOND LIMITS SHOWN IN TABLE WHILE ENGINE IS OPERATING AT FULL THROTTLE, SERVICE LIFE WILL BE GREATLY REDUCED. MOVEMENT IN EXCESS OF THESE LIMITS CAUSED BY INTERMITTENT TORQUE REACTION IS ACCEPTABLE.

"LAGGING" OR INSULATION MUST NOT RESTRAIN FLEXIBILITY OF BELLOWS.

INSTALLATION LIMITATIONS OF CATERPILLAR FLEXIBLE EXHAUST FITTING

Figure 83

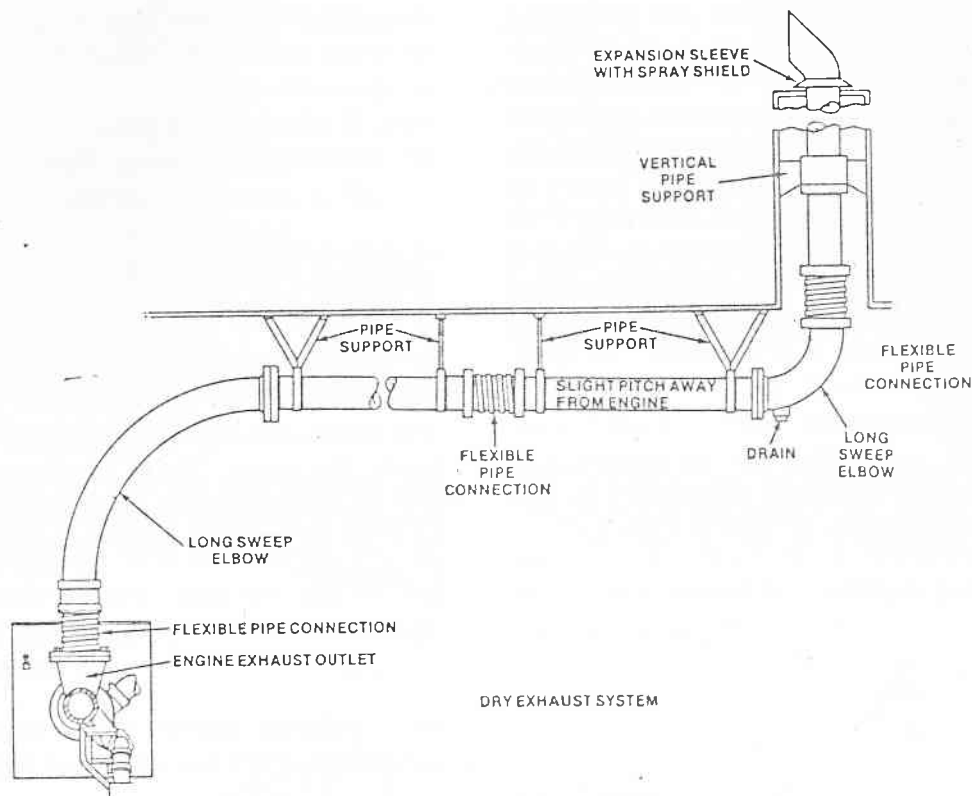


Figure 84

It is of utmost importance that the flexible pipe connection, when insulated, be done in such a way that the flexible pipe connection can expand and contract freely within the insulation. This generally requires either a soft material or an insulated sleeve to encase the flexible pipe connection.

Emissions

Gaseous exhaust emissions of diesel engines are the lowest of modern internal combustion engines. Caterpillar Engines at rated load will not exceed:

Nitrogen Oxide (NO _x)	8.75 grams/bhp-h
Carbon Monoxide (CO)	1.50 grams/bhp-h
Hydrocarbons (HC)	0.25 grams/bhp-h

Depending on configuration and rating, many engines will emit considerably less emissions.

The exhaust heat must be discharged in a manner which will not cause discomfort to personnel or a hazard to buildings or equipment. The exhaust discharge must be located away from ventilating air intakes to prevent reentry of offensive fumes and odors into the building. Introducing exhaust emissions into the discharge of a radiator blower fan is acceptable but, to avoid premature clogging of the radiator core, never allow the exhaust to pass through the radiator.

VENTILATION

Six to ten percent of the fuel consumed by a diesel engine is radiated to the surrounding air. In addition, heat originating in the generator and exhaust piping can easily be as much as the engine's radiated heat. The resulting high temperatures in the engine room could adversely affect maintenance personnel, switchgear, and generator set performance.

Engine room ventilation can be determined by the following formulae, assuming an ambient air temperature of 100° F (38° C):

$$V = \frac{H}{.0076 \times 0.24 \times \Delta T} + \text{Engine Combustion Air}$$

V = Ventilating Air (cfm)

H = Btu/min Heat Radiation

ΔT = permissible Temperature Rise in Engine Room

0.0706 = Density of Air (lb/ft³) at 100° F

0.24 = Specific Heat of Air

In installations which utilize a remote or engine-mounted radiator, the radiator fan will often provide sufficient air flow to ventilate the room. These fans are very sensitive to backpressure, so no more than 0.5 in of H₂O (0.12 kPa) total restriction can be tolerated.

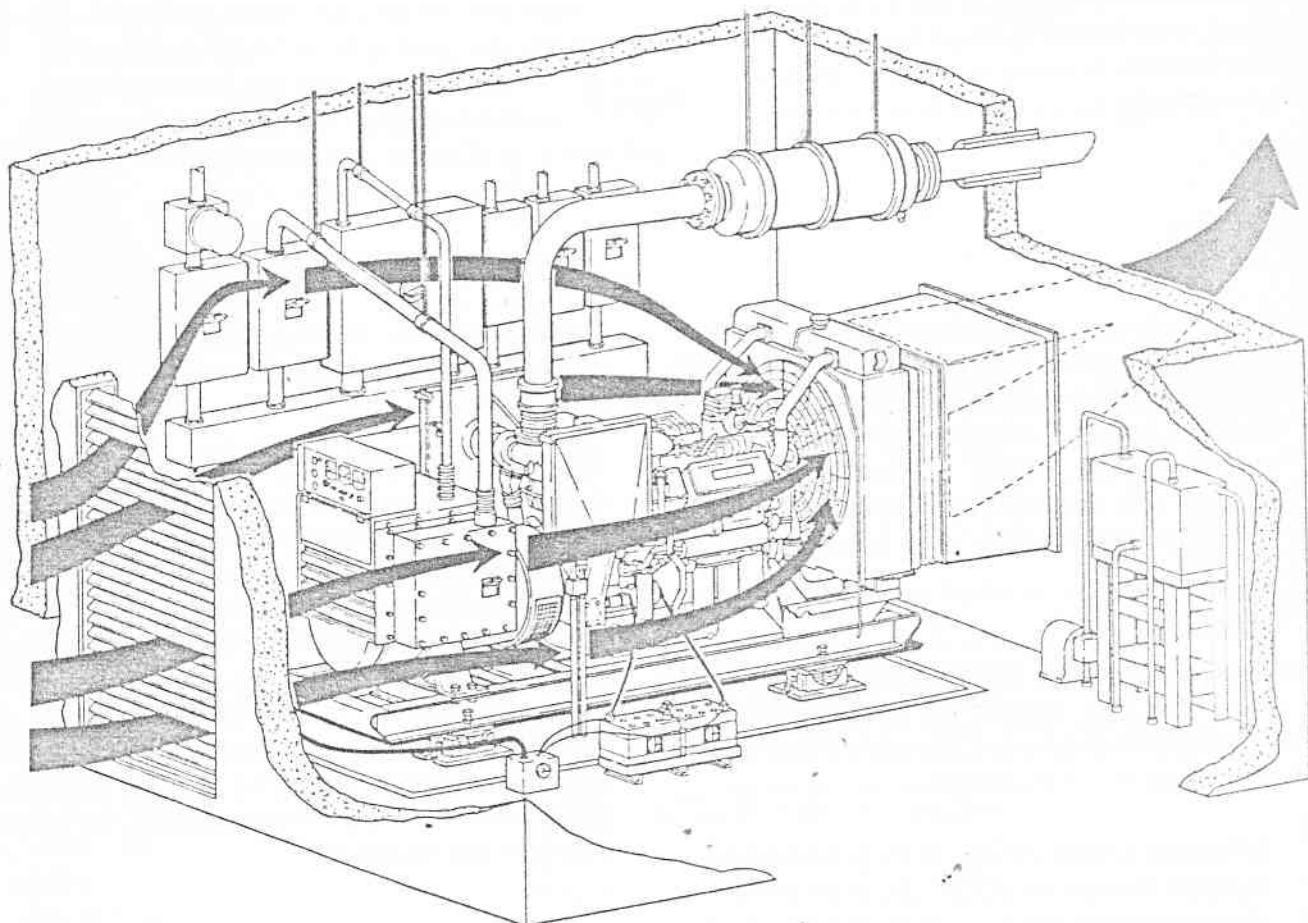


Figure 85

Ideally, clean, cool, and dry air will circulate around the switchgear, then flow through the rear of the generator, across the engine, and discharge through the radiator Figure 85. Cool air should always be available for the engine air cleaner.

The room air intake should be located to provide maximum cooling air to the generator set, yet also avoid hot stagnant air in other parts of the room. For multiple generator sets, additional openings and fans may be necessary.

Units which do not use radiator cooling will usually require a forced air draft to assure uniform ventilation. The opening for the intake air should be low, near the rear of the engine. The outlet should be located high on the opposite wall.

An air curtain which totally envelops the generator set provides ventilation without

exposing the remainder of the equipment room to high air velocities Figure 86. The radiated heat of the unit can be removed with approximately half of the air flow described in Figure 85.

A 15° F to 20° F (7° C to 10° C) temperature rise (ΔT) is a reasonable target for an engine room. However, in cold climates this may cause discomfort due to the large flow of cold air. Restrict this flow only if engine combustion air is available and engine jacket water can be adequately cooled.

Firing pressures cause a slight amount of blowby past the piston rings into the crankcase. The resulting crankcase pressure must be relieved to maintain good oil control and seal life.

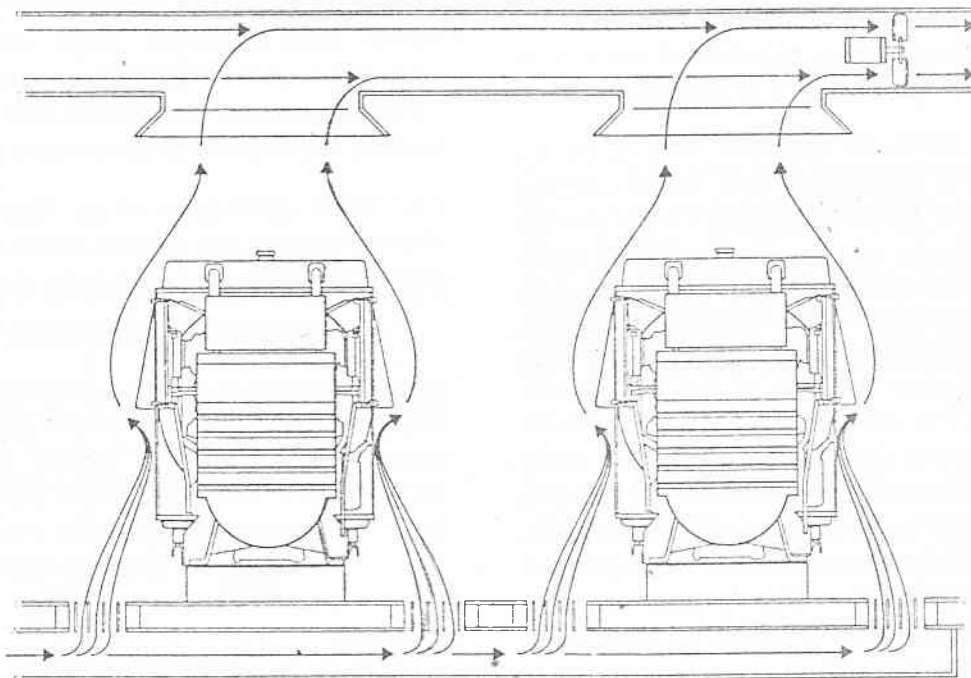


Figure 86

All generator set engines are equipped with a ventilator pipe to permit fumes to escape from the crankcase. It is recommended the ventilator outlet be piped to an outdoor vent and a dripleg employed to collect any condensation. Fumes are thus prevented from collecting in the equipment room and from clogging the engine intake air filters. In standby applications, the low operating hours place little demand on the air filters. The fumes disposal tube can be discharged immediately in front of the filter which, while possibly shortening the filter service periods, will remove crankcase fumes from the engine room without additional piping and vents.

When unusually long runs of pipe are used, as may be the case in below-ground installations, the pipe size should be increased to reduce backpressure. In some instances, it may be necessary to install a suction device in the line to aid ventilation. A length of flexible oil- and chemical-resistant tubing should be inserted in the opening (in a nonair tight manner) at the generator set ventilator outlet so that the fumes flow out of the breather with a vacuum of less than 1 in H₂O (0.25 kPa) on the crankcase.

The fumes disposal system should be so designed and installed that each engine has a separate discharge pipe. There should be no low places in the pipe that will allow condensation to collect and block the fumes passage. The maximum allowable crankcase pressure at full load is plus 1 in H₂O (0.25 kPa).

Both intake and exhaust ventilators may have louvers for weather protection. These may be movable or fixed but, if movable, they should be actuated by a pneumatic, electric, or hydraulic motor. Never depend on the air pressure developed by the radiator fan to move the vanes.

Movable louvers can be arranged to provide circulation inside the room until jacket water temperatures reach 190° F (88° C)

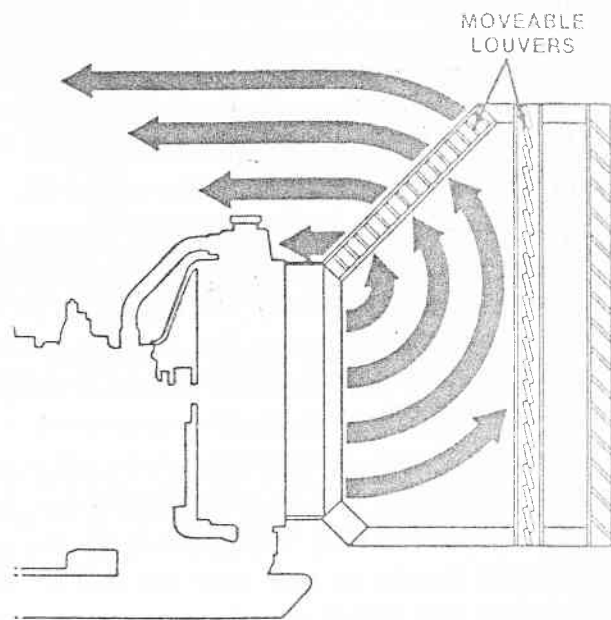


Figure 87

Figure 87. At that time the radiator must be furnished with sufficient cooling air to prevent the engine jacket water from overheating. If ventilating fans are used, it is good practice to use a number of small fans rather than a single large unit. Selective operation of the fans can compensate for varying ambient temperatures while maintaining the desired engine room temperature.

For initial estimates of air flow required to maintain a desired engine room temperature rise, the following formula may be used:

$$\text{cfm} = \frac{400 \times \text{hp}}{T}$$

Where: hp = Maximum engine horsepower.
T = Equipment room temperature rise above ambient degrees F.

Or:

$$\text{m}^3/\text{s} = \frac{0.34 \times \text{hp}}{T}$$

Where: hp = Maximum engine horsepower.
T = Equipment room temperature rise above ambient degrees C.

The air flow should be increased 10% for every 2,500 ft (760 m) above sea level.

COOLING SYSTEM

A heat balance chart for a modern diesel engine indicates that almost one-third of the fuel required for engine operation is absorbed by the jacket water in the form of heat. This heat must be totally removed to assure dependable engine performance.

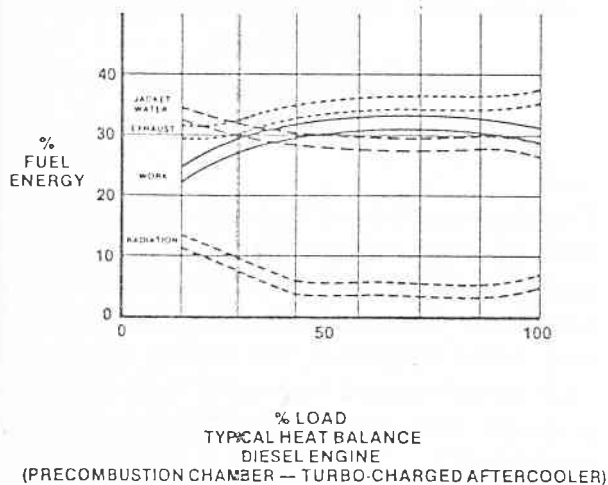


Figure 88

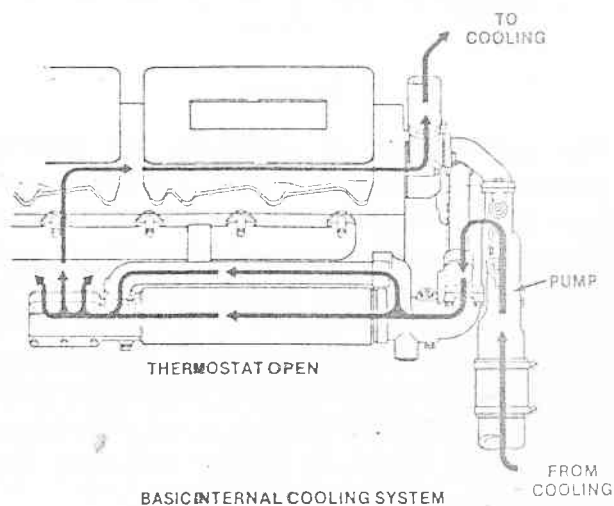
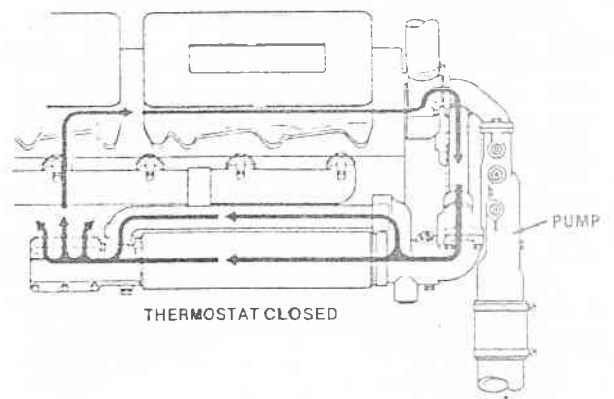


Figure 89

The manner in which this heat is removed is regulated by engine thermostats.

Efficient engine operation is encouraged by disconnecting the external cooling system until jacket water temperatures exceed 175° F (79° C). Never operate without thermostats when utilizing the normal 175° F (79° C) cooling system.

Most generator set engines are designed for a water temperature differential (outlet minus inlet) of 10° F to 15° F (5.5° C to 8.3° C). The high temperature limit of water leaving the engine is determined by cooling system design. In a standard system operating with a 4 to 7 psi pressure cap, maximum, top tank temperature is 210° F (99° C). This limit prevents steam from forming in the engine water jacket. The following chart illustrates the effect of pressure on the boiling point of water at various altitudes.

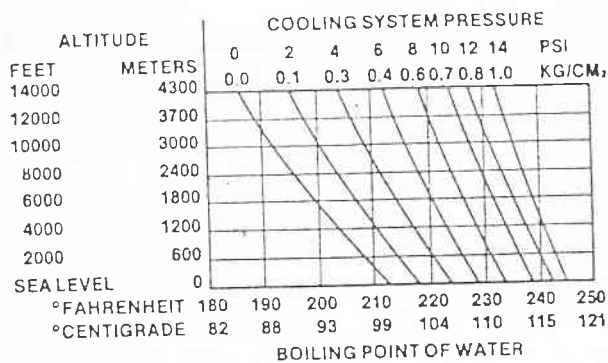


Figure 90

For each pound of pressure, the boiling point is raised about 3° F (2° C). Slight system pressure minimizes pump cavitation (voids in water) even at high altitude and results in increased pump efficiency. For elevations above 10,000 ft. a higher rated pressure cap may be required. The addition of alcohol or other volatile antifreeze coolants will lower the boiling point even more. In contrast, ethylene glycol solutions will raise the boiling point Figure 94.

System Design

The amount of water that must be circulated through an engine to ensure adequate cooling is determined by the rate at which the engine rejects heat to the jacket water and by the allowable jacket water temperature rise. When calculating heat rejection, close attention to exact engine power rating and configuration is necessary. Water-cooled exhaust manifolds can increase heat rejection 15% over that of dry manifolds. Watercooled manifolds adversely affect turbocharger performance and may cause a power deration.

The required water flow rate in the jacket or any other part of the main or auxiliary cooling system may be calculated from the following formula:

$$\text{Flow (gal/min)} = \frac{\text{Heat Rejection Rate (Btu/min)}}{\Delta T (^{\circ}\text{F}) \times 8.1 \text{ lb/gal}}$$

Where ΔT = Allowable Temperature Rise, °F

8.1 = Density of Water, lb/U.S. gal 175°F, 80°C

$$\text{Flow (liter/min)} = \frac{\text{Heat Rejection Rate (K cal/min)}}{\Delta T (^{\circ}\text{C}) \times 0.9946 \text{ kg/liter}}$$

Where ΔT = Allowable Temperature Rise, °C

0.9946 = Density of Water, kg/liter

The piping and heat transfer equipment connected to an engine offers a resistance to jacket water flow. This resistance represents an external pressure head against which the engine-driven pump must work. The jacket water flow rate is reduced for a given size pump as the external head increases.

To ensure adequate coolant flow is maintained, the external head losses must be calculated and compared to the capability of the water pump. In installations where excessive external head is encountered, a pump with additional pressure capacity must be specified. If a high capacity pump is installed in series with the standard engine pump, the total pressure head imposed on the engine pump inlet must be less than 25 psi. Modifications of the external system may be necessary to prevent cavitation of the high capacity pump.

Friction head losses are a function of the pipe size, number and type of fittings and valves used, the coolant flow rate, and the loss contributed by the heat transfer device. Once the required coolant flow rate has been determined, pump performance characteristics will establish maximum allowable external head against which it will deliver the required flow.

Flow of the coolant in the system must be maintained in a velocity range to achieve optimum heat transfer without damage to system components by erosion. Jacket water external circuit velocities in the range of 2-8 fps (0.6-2.5 m/s) are acceptable. Raw or sea water circuit velocities should be in the range of 2-6 fps (0.6-1.9 m/s).

Figures 91 and 92 can be used to convert water flow to velocity in pipes and tubes.

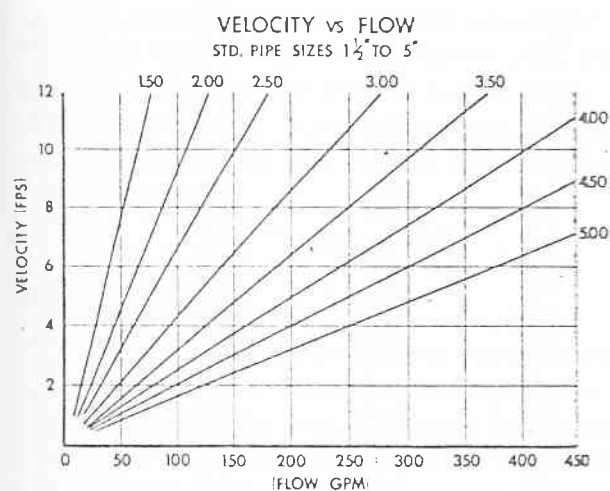


Figure 91

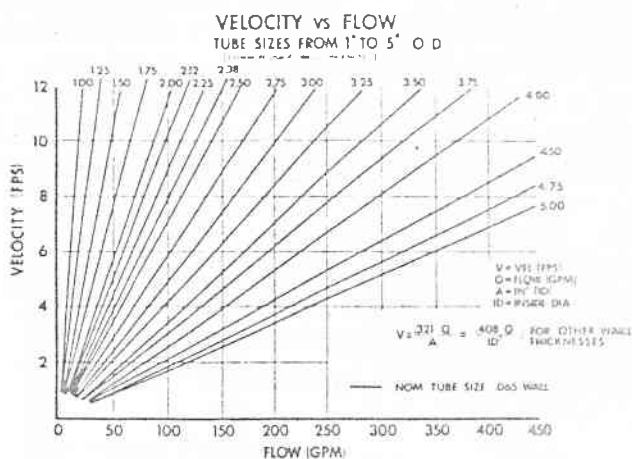


Figure 92

Consult the manufacturer's specification sheets for information on friction head loss through the heat transfer device. Pipe and fitting losses may be determined by means of Figure 93. To discourage resistance, minimize the number of bends in the piping. Long sweep elbows and gate-type valves should be used when possible.

**TYPICAL FRICTION LOSSES OF WATER IN PIPE
(OLD PIPE)**

FLOW		HEAD LOSS IN FEET PER 100 FT. (m per 100 m)								FLOW	
gpm	(l/s)	3/4" (19.05 mm)	1" (25.4 mm)	1-1/4" (31.75 mm)	1-1/2" (38.1 mm)	2" (50.8 mm)	2-1/2" (63.5 mm)	3" (76.2 mm)		gpm	(l/s)
5	.34	10.5	3.25	0.84	0.40	0.16	0.05	0.07		5	.34
10	.63	38.0	11.7	3.05	1.43	0.50	0.17	0.15		10	.63
15	.95	80.0	25.0	6.50	3.05	1.07	0.37	0.25		15	.95
20	1.26	136.0	42.0	11.1	5.20	1.82	0.61	0.38		20	1.26
25	1.58	4" (101.6 mm)	64.0	16.6	7.85	2.73	0.92	0.54		25	1.58
30	1.9		89.0	23.0	11.0	3.84	1.29	0.71		30	1.9
35	2.21		119.0	31.2	14.7	5.10	1.72	0.91		35	2.21
40	2.52		152.0	40.0	18.8	6.60	2.20	1.16		40	2.52
45	2.84		5" (127 mm)	50.0	23.2	8.20	2.76	1.38		45	2.84
50	3.15			60.0	28.4	9.90	3.32	1.92		50	3.15
60	3.79			85.0	39.6	13.9	4.65	2.57		60	3.79
70	4.42			113.0	53.0	18.4	6.20	2.93		70	4.42
75	4.73			129.0	60.0	20.9	7.05	3.28		75	4.73
80	5.05			145.0	68.0	23.7	7.90	4.08		80	5.05
90	5.68			6" (152.4 mm)	84.0	29.4	9.80	4.96		90	5.68
100	6.31				102.0	35.8	12.0	7.55		100	6.31
125	7.89				7" (177.8 mm)	54.0	17.6	10.5		125	7.89
150	9.46					76.0	25.7	14.1		150	9.46
175	11.05					8" (203.2 mm)	34.0	17.8		175	11.05
200	12.62						43.1	22.3		200	12.62
225	14.20						54.3	27.1		225	14.20
250	15.77						65.5	32.3		250	15.77
275	17.35						9" (228.6 mm)	38.0		275	17.35
300	18.93							44.1		300	18.93
325	20.5							50.5		325	20.5
350	22.08							10" (254 mm)		350	22.08
375	23.66									375	23.66
400	25.24									400	25.24
425	26.81									425	26.81
450	28.39									450	28.39
475	29.97									475	29.97
500	31.55									500	31.55
750	47.32									750	47.32
1000	63.09									1000	63.09
1250	78.86									1250	78.86
1500	94.64									1500	94.64
1750	110.41									1750	110.41
2000	126.18									2000	126.18

Flow Restriction of Fittings Expressed as Equivalent Feet of Straight Pipe

Size of Fitting	2"	2-1/2"	3"	4"	5"	6"	8"	10"	12"	14"	16"
90 Ell	5.5	6.5	8	11	14	16	21	26	32	37	42
45 Ell	2.5	3	3.8	5	6.3	7.5	10	13	15	17	19
Long Sweep Ell	3.5	4.2	5.2	7	9	11	14	17	20	24	27
Close Return Bend	13	15	18	24	31	37	51	61	74	85	100
Tee — Straight Run	3.5	4.2	5.2	7	9	11	14	17	20	24	27
Tee — Side Inlet or Outlet	12	14	17	22	27	33	43	53	68	78	88
Globe Valve Open	55	67	82	110	140						
Angle Valve Open	27	33	41	53	70						
Gate Valve Fully Open	1.2	1.4	1.7	2.3	2.9	3.5	4.5	5.8	6.8	8	9
Gate Valve Half Open	27	33	41	53	70	100	130	160	200	230	260
Check Valve	19	23	32	43	53						

Figure 93

Suction head on the pump must not be significantly below atmospheric pressure. Inlet piping should have an internal diameter at least as great as that furnished on the engine and include a minimum number of bends. Bottom tank of the radiator must also have a greater cross sectional area than that of the inlet pipe.

The static head is determined by the maximum height the coolant water is raised once it leaves the engine. Large static heads may be encountered in installations where the radiator or heat exchanger is located on the roof. At heights above 57 ft (17.4 m) the static head developed can cause leakage at the engine pump seals. A separate external cooling system is then required to relieve the engine system from this pressure.

Water Treatment

Of prime consideration in any closed cooling system is the proper treatment of the cooling water. The water should be treated to ensure that neither corrosion nor scale forms at any point in the system. Usually water hardness is expressed in grains per gallon; one grain being equal to 17.1 parts per million (ppm) expressed as calcium carbonate. Water containing up to 3.5 grains per gallon is considered soft and causes few deposits.

Usable water must have the following characteristics:

pH	6.5-8
Chloride and Sulfate	100 ppm
Total Dissolved Solids	500 ppm
Total Hardness	200 ppm

Water softened by removal of calcium and magnesium is acceptable.

A corrosion inhibitor is then added to the system to keep it clean, reduce scale and foaming, and provide pH control. With the addition of an inhibitor, a pH of 8.5 to 10 should be maintained. The inhibitor must not damage hoses, gaskets, or seals.

Caterpillar cooling inhibitor is compatible with ethylene glycol base antifreeze but cannot be used with Dowtherm 209. A 3% to 6% concentration of inhibitor is recommended. Soluble oil or chromate solution should not be used.

NOTE: In cases where there is a possibility of the cooling water coming into contact with a domestic water supply, water treatment may be regulated by local codes.

Antifreeze Protection

Installations which expose the engine coolant to subfreezing temperatures must add antifreeze to the water system. Ethylene glycol or Dowtherm 209 are recommended to protect against freezing, and to inhibit corrosion. Borate-nitrite solutions such as Caterpillar inhibitor or NALCO 2000 are compatible only with ethylene glycol, and can be used to replenish the original corrosion inhibitors in the antifreeze.

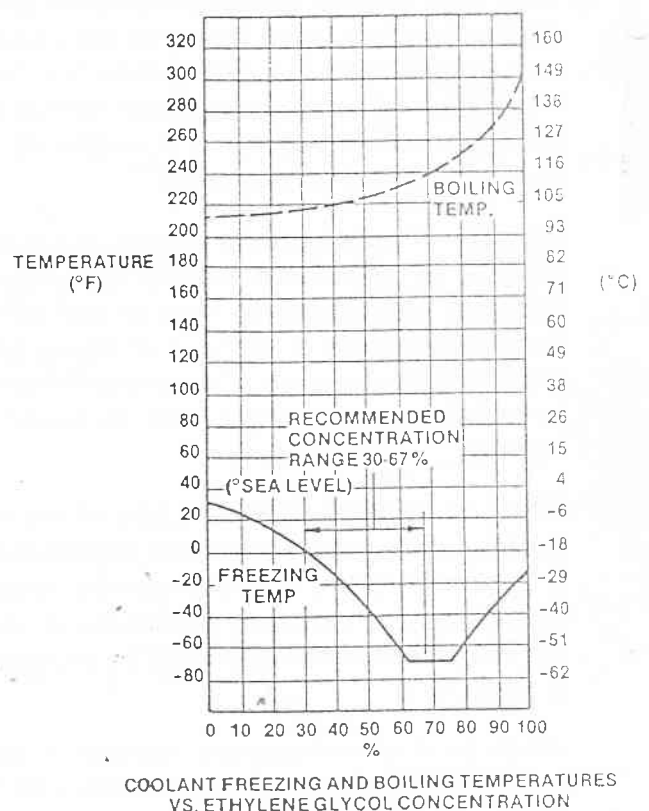


Figure 94

Figure 94 defines the concentration of ethylene glycol required for the lowest ambient temperature. It also describes the effect on the coolant boiling temperature, which will reduce coolant afterboil. The concentration should exceed 30% to assure protection against corrosion, but above 60% will needlessly penalize its heat transfer capabilities. Generally, a radiator must be derated 2% for each 10% of antifreeze concentration. Use of antifreeze year around will require increasing the radiator capability at least 6° F (3.3° C).

Types of Cooling

Radiator cooling is the most common and reliable method used to cool generator sets. As with all cooling systems, radiators are usually sized for a heat rejection load a minimum of 15% greater than the maximum full-load heat rejection rate of the generator set engine. This allows for overload conditions and system deterioration. This 15% should be added after a careful calculation has been made of the radiator size required to accommodate the maximum heat rejection rate (under normal full-load operating conditions) at maximum ambient operating temperature.

Altitude affects radiator sizing. Increased air flow is required at higher altitudes to maintain equivalent air flow to that at sea level. A reduction of 2.5° F (1.4° C) per 1,000 ft (304 m) of elevation is a typical reduction in radiator performance due to lower air density.

When louvers are used, the size of the wall opening should be increased approximately 25% due to the louver assembly restriction. If common window screening is used, the size of the opening should be increased at least 40%.

When an engine-mounted radiator is used and the generator set is installed in the center of the room, a blower fan can be used and a duct provided to the outside

Figure 95. This prevents recirculation and high equipment room temperatures. Some generator set packages have as standard a radiator duct flange for ease of installation. The duct is as short and direct as possible; its cross-section area should be as large or larger than the radiator core to minimize backpressure. The anticipated backpressure for a proposed duct design should be less than 0.5 in (1.3 cm).

Radiators

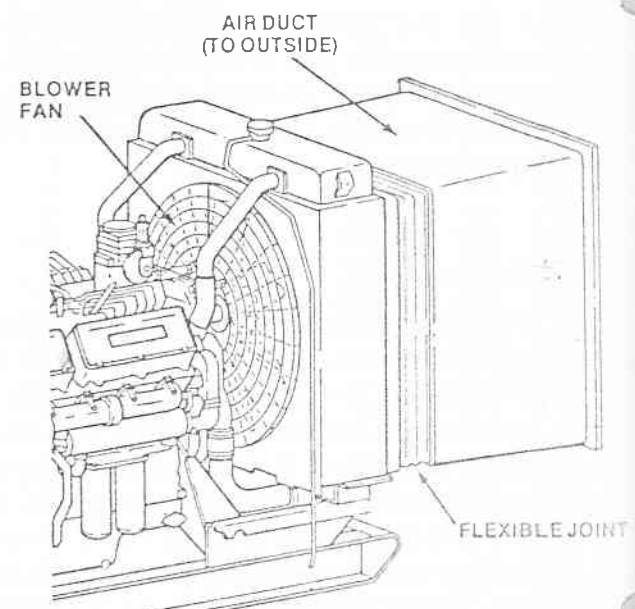


Figure 95

When selecting radiator location, consider fan noise. Noise may be transmitted through the air inlet as well as outlet. As further precaution against noise and vibration, the ducting should not be rigidly attached to the radiator.

Also consider the direction of the prevailing winds so the wind does not act against the fan. One form of wind protection for a wall-mounted radiator installation is a baffle set several feet from the wall. Another

method is to install an air duct outside the wall to direct the air outlet (or inlet) vertically. A large radius bend and turning vanes should be used to prevent turbulence and airflow restriction. For basement installations, pits can be constructed for both the air intake and output openings.

Remote Radiators

On installations where it is desirable to locate the radiator at some distance from the

generator set, i.e., on a roof, outdoors or in another room, a remote radiator can be used. Remote-mounted radiator systems require special attention due to the added restriction imposed on the cooling water flow by additional piping. Careful calculations should be made to determine whether a higher output pump is necessary.

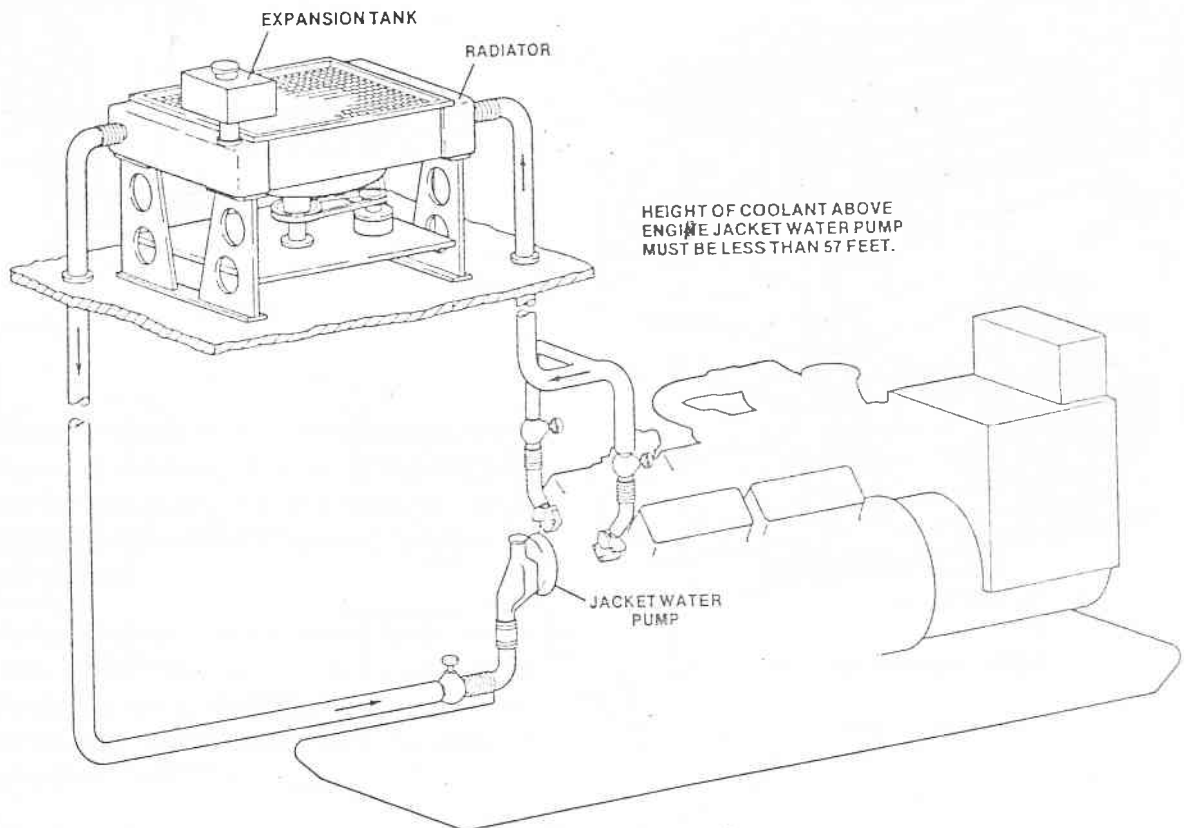


Figure 96

Rooftop radiators must not be higher than 57 ft (17.4 m) above the engine pump to avoid pump seal leakage. An automatic make-up water control and/or a low water alarm are desirable features in a remote radiator system due to the possible lack of attention a remote system receives.

While it is always preferable in multiple generator set installations to provide separate cooling systems for each engine, there may be instances where a single radiator is

used. Such a design must be analyzed by a cooling system engineer as well as the generator set supplier.

Hot Wells

A hot well system is sometimes used when the static head exceeds 25 psi (172 kPa), or when a boost pump imposes excessive dynamic head. It may also be used to save the cost of antifreeze in an extended system.

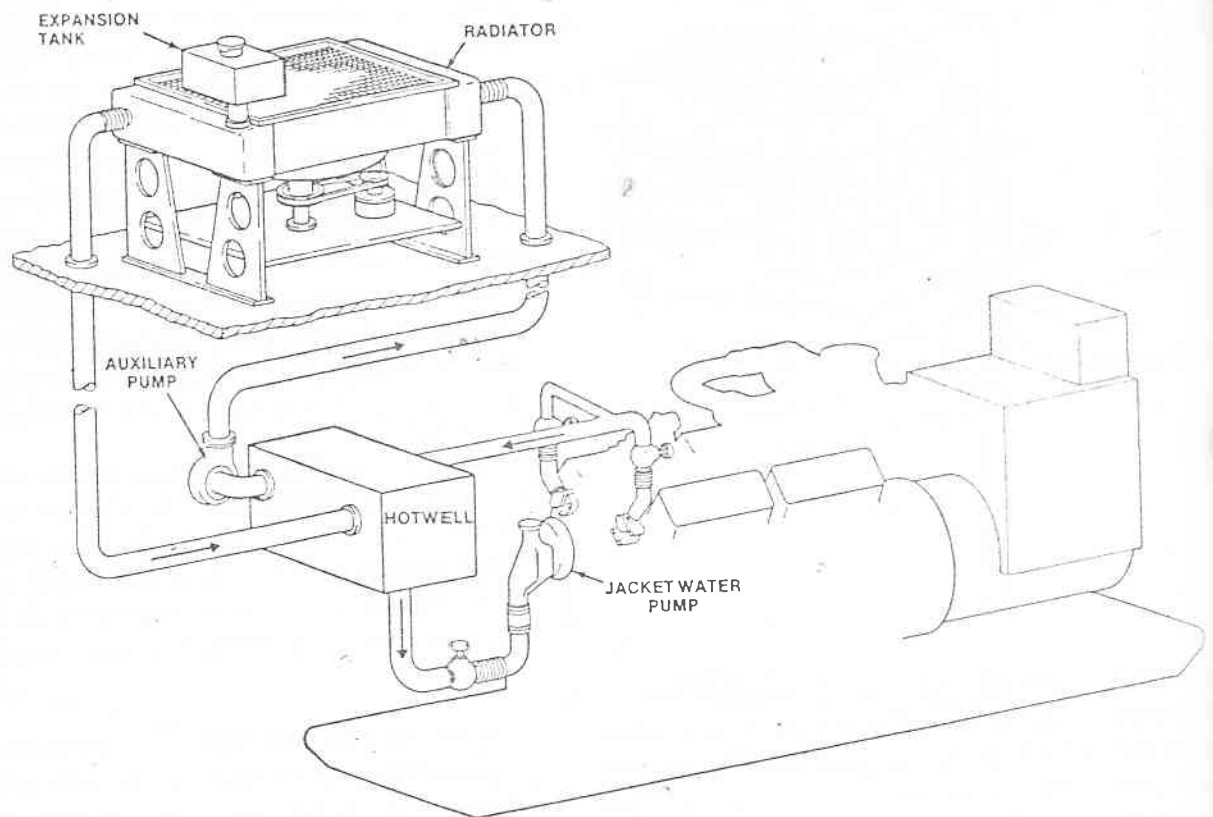


Figure 97

The system incorporates a mixing tank of sufficient size to accommodate the total content of the remote cooling device and connecting piping. A baffle divides the tank into a hot and cold side, but is open sufficiently to allow full engine flow at startup. Baffles are also used as water enters the tank to discourage aeration.

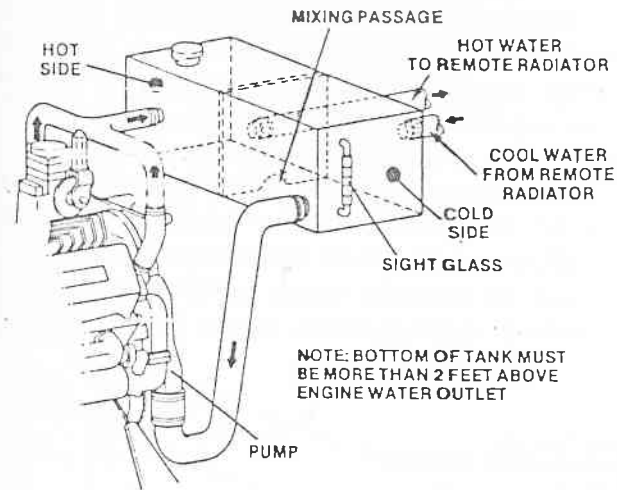
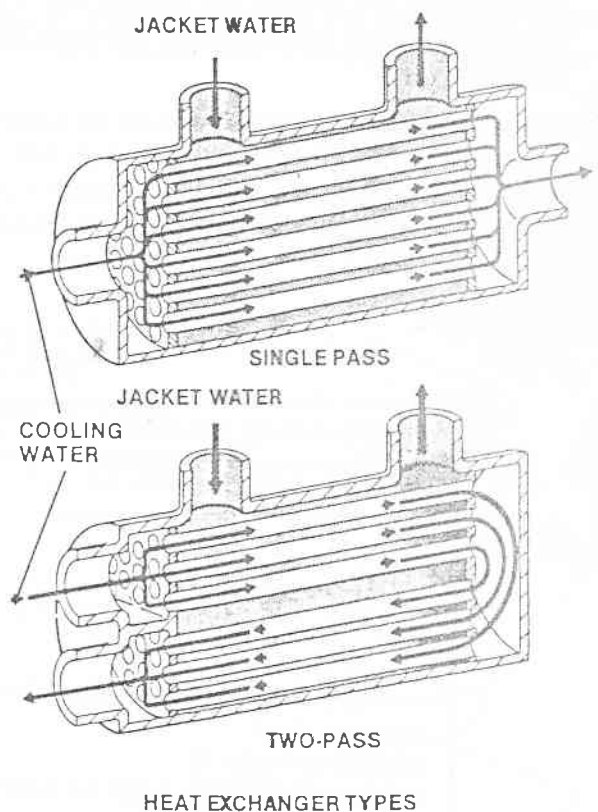


Figure 98

once. When using a single-pass exchanger, the raw water should flow through the exchanger in a direction opposite to the flow of jacket coolant to provide maximum differential temperature and heat transfer. This results in improved heat exchanger performance. In a two-pass exchanger, cooling will be equally effective using either of the jacket water connection points for the input and the other for return.



HEAT EXCHANGER TYPES

Figure 99

The auxiliary pump must operate whenever the engine is running. Allowing the engine to warm before pumping to a remote radiator can cause the radiator core to fail due to thermal shock.

If the empty radiator is exposed to extreme cold, the initial flow of coolant can freeze and block the core. Antifreeze must be included in the water treatment to assure uninterrupted flow.

Heat Exchanger

Most shell-and-tube heat exchangers are of either the single-pass or the two-pass type. This designation refers to the flow in the raw water circuit of the exchanger. In the two-pass type the raw water flows twice through the compartment where jacket water is circulated; in the single-pass type only

For a given jacket water flow rate, the performance of a heat exchanger depends on both the raw water flow rate and differential temperature. To reduce tube erosion, the flow rate of the raw water through the tubes should not exceed 6 fps (183 m/s). The heat exchanger should be selected to accommo-

date the raw water temperature and flow rate needed to keep the temperature differential of the jacket water below about 15° F (8.3° C) at maximum engine heat rejection. Thermostats must be retained in the jacket system to assure that the temperature of the jacket water coolant returned to the engine is approximately 175° F (79° C).

Heat exchangers must be sized to accommodate a heat rejection rate 15%-30% greater than the established engine full-load heat rejection rate, depending on the fouling factor required. Typical fouling resistances are shown on Figure 100. Standard Caterpillar exchangers incorporate a 0.001 factor.

Since heat exchanger tubes can be cleaned more easily than the surrounding jacket, the raw water usually is routed through tubes and the engine coolant through the shell.

Submerged Pipe — Keel Cooling

Special types of water-to-water heat exchangers are those involving keel coolers on ships and submerged pipe cooling. To estimate the surface area required to dissipate the jacket water heat requires assumptions that:

1. The ship is moving at least 8 knots, or raw water is flowing over the submerged pipes.
2. The raw water is below 85° F (30° C).

The surface area can then be estimated as 0.67 ft² (0.062 m²) per engine kW. Exact calculations must take into account the type of material used, protective coatings, normal deterioration of the inner and outer

FOULING RESISTANCES FOR WATER

TEMPERATURE OF HEATING MEDIUM	UP TO 240°F.	
TEMPERATURE OF WATER	125°F. OR LESS	
TYPES OF WATER	WATER VELOCITY FT. SEC.	
	3 FT. AND LESS	OVER 3 FT.
SEA WATER	.0005	.0005
BRACKISH WATER	.002	.001
COOLING TOWER AND ARTIFICIAL SPRAY POND:		
TREATED MAKEUP	.001	.001
UNTREATED	.003	.003
CITY OR WELL WATER (SUCH AS GREAT LAKES)	.001	.001
RIVER WATER:		
MISSISSIPPI	.003	.002
CHICAGO SANITARY CANAL	.008	.006
HARD (OVER 15 GRAINS GAL.)	.003	.003
ENGINE JACKET	.001	.001
TREATED BOILER FEEDWATER	.001	.0005

Figure 100

surfaces, plant growth, and variations in water temperature. In the case of keel coolers, varying ship's speed must also be considered. Due to these many factors, the heat exchangers must be considerably oversized to assure adequate engine cooling.

Expansion Tank

Unlike radiators, heat exchangers have no built-in provision for jacket water expansion. A surge (expansion) tank or tanks must be included in a heat exchanger system. A factory-designed tank is normally

specified to assure proper performance of the total system.

Water expands about 5% its volume between 32° F and 212° F (0° C and 100° C). The expansion tank should have a capacity of at least 15% of the system water volume for this expansion plus a reserve. It must be vented to the atmosphere or incorporate a pressure cap to assure system pressure and located to prevent the formation of a vacuum, a primary cause of cavitation on the suction side of the pump.

Provision must be made to deaerate the jacket water to prevent the formation of air pockets within the system and minimize

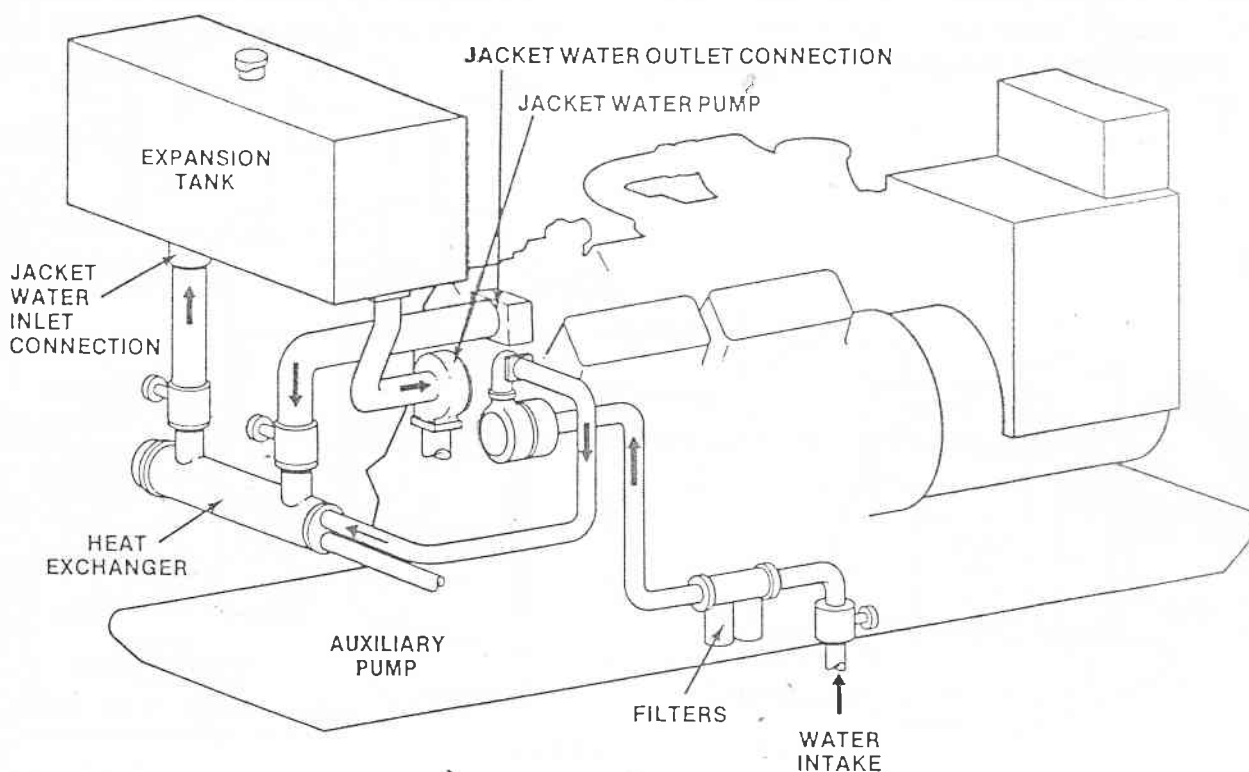


Figure 101

pump cavitation. Entrained air encourages both corrosion and erosion in the engine. Coolant may be lost because air will expand more than water when it is heated. Entrained air is caused by air trapped during a fill operation, combustion gases leaking into the cooling system, leaks in piping (particularly on inlet side of pump), or low water level in the expansion tank. A low velocity area must be provided where deaeration can occur. The entrained air will separate from the water if the tank is sized and baffled to slow the full water flow to less than 2 fps (0.6 m/s).

The expansion tank is the highest point in the jacket water circuit. The heat ex-

changer must be mounted at a level lower than the coolant in the expansion tank, preferably several feet. The system should be designed so the total jacket water flows from the engine outlet to the heat exchanger, to the expansion tank and back to the jacket water pump inlet. This facilitates purging of air and also creates a positive pressure at the jacket water pump inlet. If the heat exchanger is to be remote-mounted, as in Figure 102, it is good practice to locate it in a minimum vibration area, with flexible fittings between the heat exchanger and the engine.

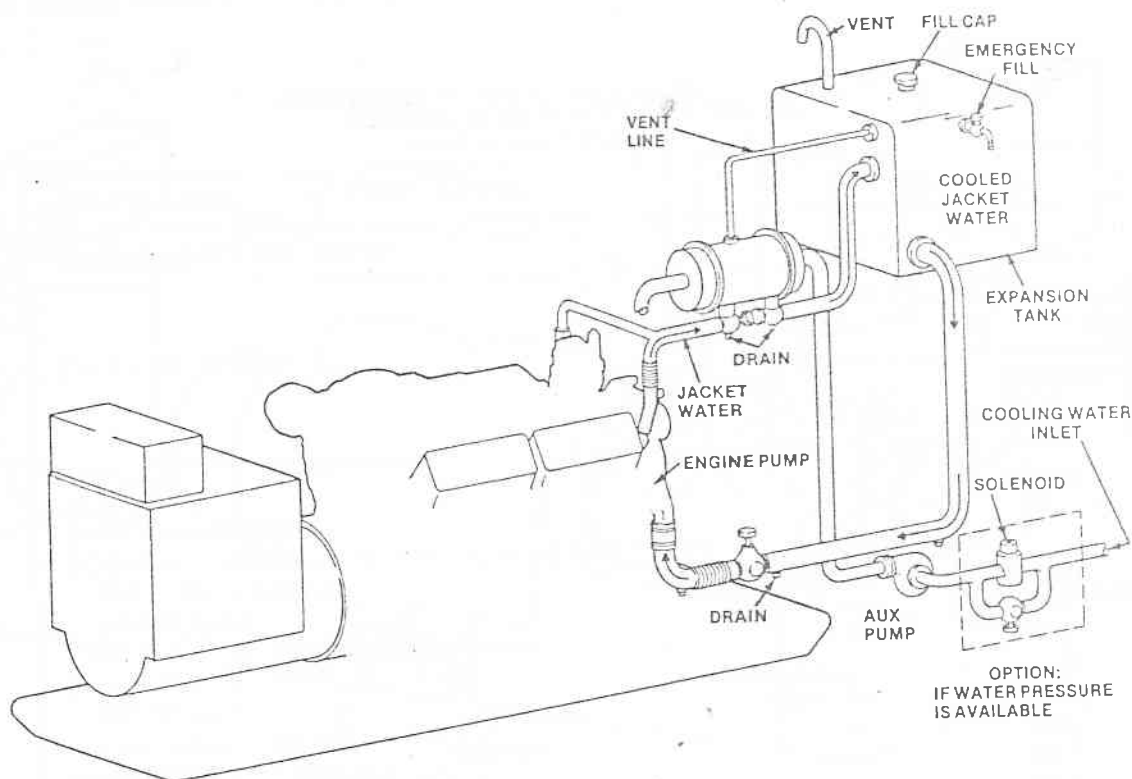


Figure 102

HEAT RECOVERY

A reciprocating engine converts only about 33% of its input fuel energy into mechanical power. The remainder of the fuel energy is transformed into heat and is carried from the engine by the jacket water, exhaust, and radiation.

The 30% contained in the jacket water can be totally recovered. Watercooled manifolds are used to allow the engine coolant to carry the major portion of the rejected heat. About half of the 30% carried by the exhaust is economically recoverable. Total heat recovery can result in fuel efficiencies approaching 75%.

The heat recovery design which is best suited for any installation will depend on a great many considerations, both technical and economic. However, the chief function of any design is to **cool the engine**. Provision must be made to cool the engine even when the demand for heat is low, but power is still required.

Heat recovery methods are generally grouped into normal temperature (200° F) and high temperature (250° F). High temperature techniques can be further divided into solid water (250° F, 20 psi), and ebullient (250° F, 15 psi) systems.

Normal Temperature

This system utilizes normal jacket water temperatures (about 200° F) and a shell and tube heat exchanger to transfer rejected heat to a secondary circuit — usually water. An exhaust heat recovery boiler or muffler may also be included in the system. If included, coolant must flow through the heat recovery device whenever the engine operates. Removal of the engine thermostats will prevent the sudden thermal shock of coolant on hot exhaust surfaces. Figure 103 illustrates a flow diagram for this system.

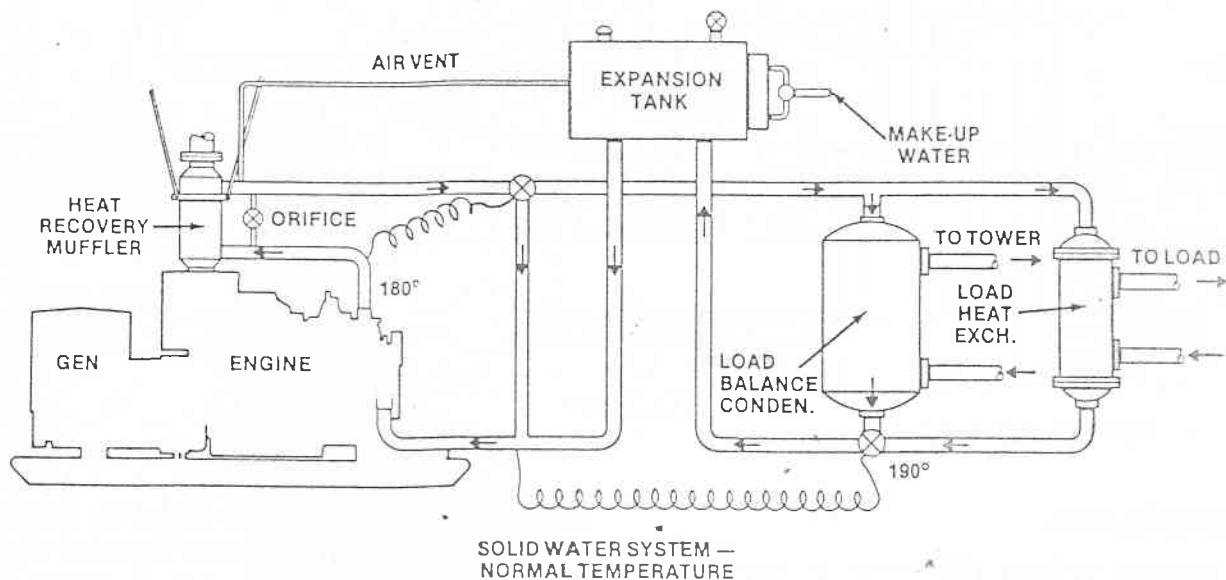


Figure 103

High Temperature — Solid Water

This system utilizes elevated jacket coolant temperatures (220°F to 250°F , recorded at engine outlet) and functions essentially the same as the normal temperature hot water system except for the pressure required in the circulating systems, especially in the engine coolant circuit. In this system, a pressure control must be provided in the engine coolant circuit, assuring a pressure at all times during operation of 4 or 5 psig above the pressure at which steam will

form. The source of this pressure may be a static head imposed by an elevated expansion tank or controlled air pressure in the expansion tank. For 250°F water temperature, this pressure should be approximately 20 psig at the engine. Also, all water circulating pumps, primary and secondary, must be suitable for use with the elevated temperatures and pressures. Conventional engine jacket water pumps are not suitable for this service. Figure 104 illustrates a flow diagram for this system.

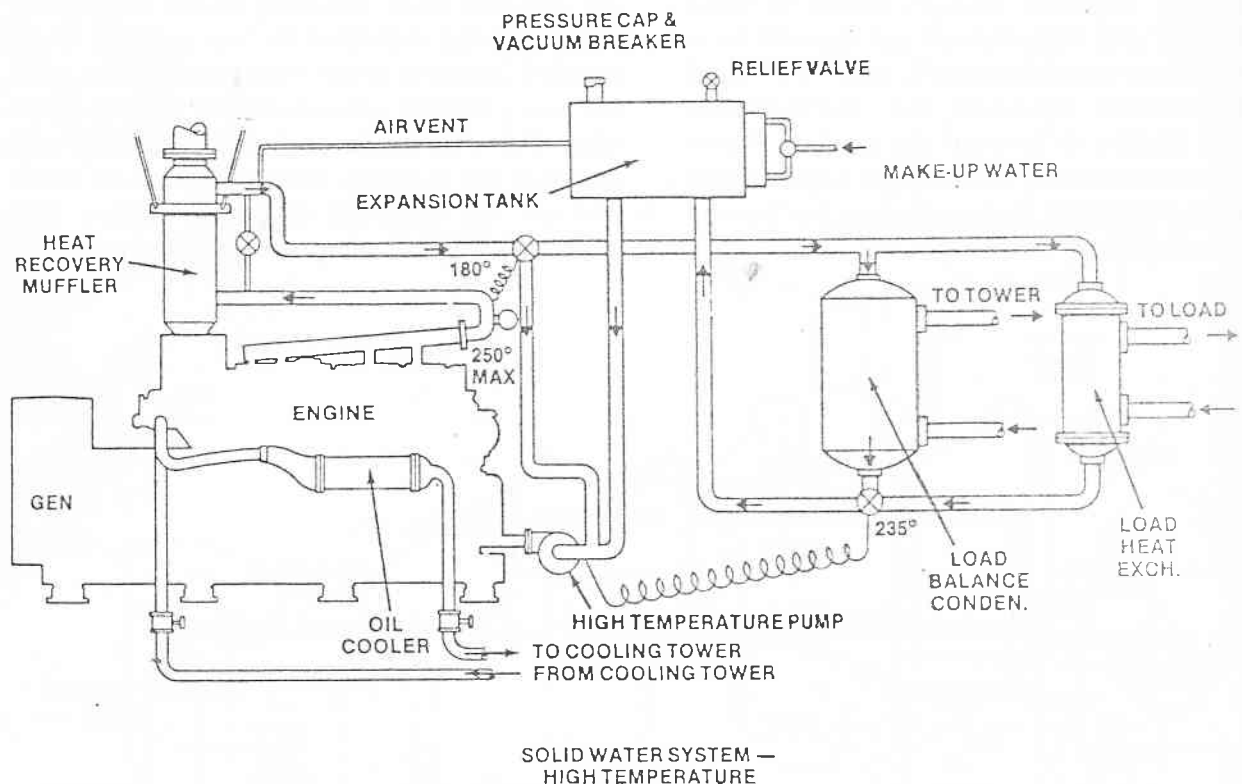


Figure 104

Ebullient System

This system utilizes the "heat of vaporization" to remove rejected heat from the engine. Steam, as such, however, is not allowed to collect within the engine but is moved through the water passages, along

with the high temperature water by thermal action, to a steam separator located at an elevation somewhat above that of the engine. No jacket water pump is required with this system. While the temperature differential between "water in" and "water out"

of the engine in this system is usually quite low (2°F to 3°F), flow through the engine is assured by the change in coolant density as it gains heat from the engine. The higher temperature coolant being lighter creates a pressure differential between the water inlet and water outlet connections to the engine. Almost all of the heat gain in the coolant is added in the form of heat of vaporization. Figure 105 illustrates the basic elements of an ebullient system.

Obviously, any number of arrangements are possible. In some instances the exhaust gas

boiler, or muffler, and the steam separator are combined into a single "packaged" unit — one packaged unit being used for each engine as illustrated by Figure 106. Other heat recovery equipment available combines the exhaust gas boiler and the steam separator in a single unit and, in addition, includes a direct-fired section in the exhaust boiler which serves to eliminate the need for an auxiliary boiler. Such units can be designed to serve two engines each. However, to do so requires a more complex exhaust piping system with the steam separator located well above the engine.

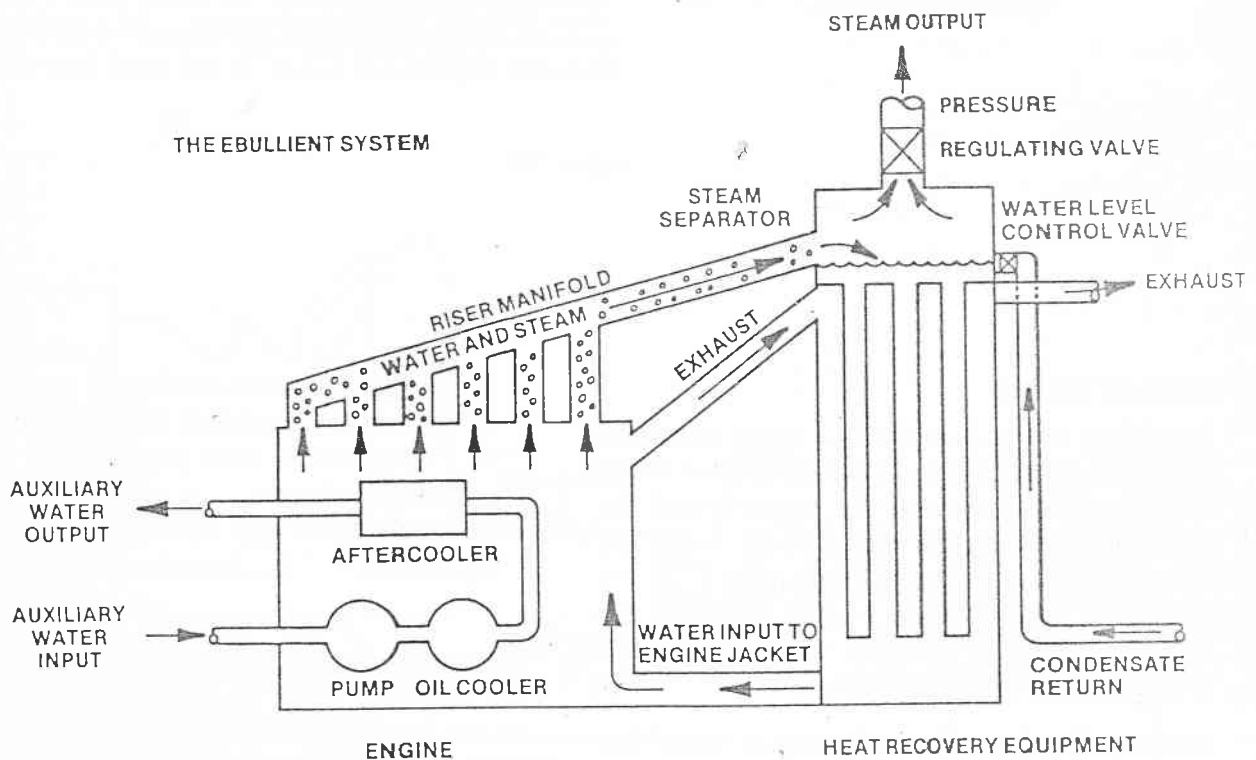


Figure 105

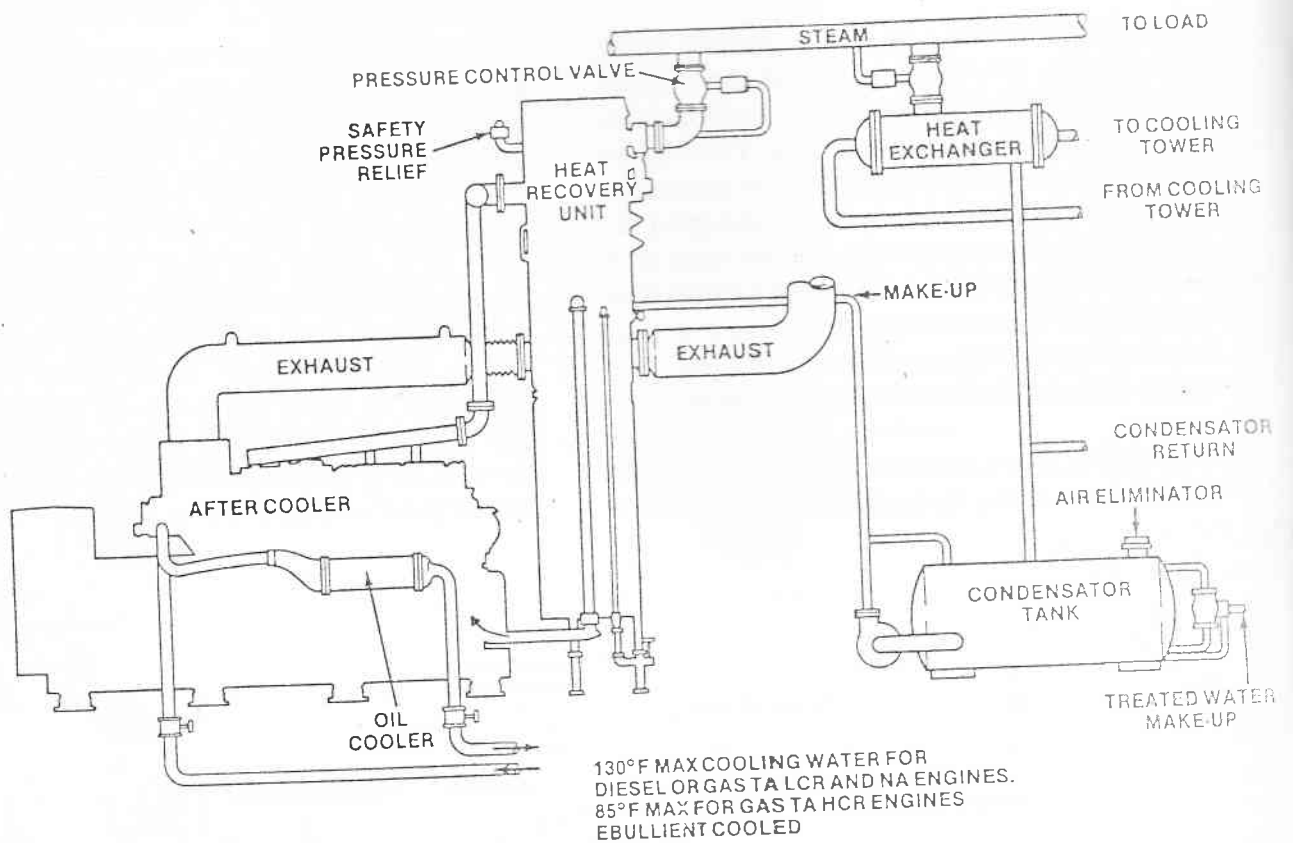


Figure 106

Cooling Towers

A cooling tower is usually a more economical method of cooling than a radiator when the approach between the coolant and the air is closer than 10° F. It cools water by evaporation to a temperature near 5° F the wet bulb temperature of the ambient air. Approximately 1% of the water circulated is normally lost to evaporation.

When evaporation occurs, about 1,000 Btu of heat is transferred for every pound of water lost. This heat contained in the water vapor is known as the latent heat of vaporization.

Selection of a cooling tower or radiator, or even the type of tower, will depend on several factors:

1. Availability and quality of water,
2. Water and ambient air temperatures,
3. Temperature and pressure of coolant temperature,
4. Costs, first and operating,
5. Space.

The tower should be located so the prevailing summer wind is in the same direction as the tower discharge air. Sufficient clearance on all sides of the tower will encourage good air circulation. To minimize noise, the tower should be positioned away from windows or building vents. Refuge from trees and birds may be anticipated, and water filters must be included in the tower return line to prevent clogging of the cooling system.

FUEL SYSTEM

Bulk Storage

The fuel supply system must assure the diesel engine of a continuous and clean supply of fuel. Bulk fuel is usually stored in a large tank, and the fuel transferred to a smaller tank (day tank) near the engine by means of an electric motor-driven pump. The system must be located and constructed in accordance with good safety practices and local codes. Any flexible nonmetallic lines used to route the fuel inside the building should meet fire resistant qualifications similar to that specified by the U.S. Coast Guard Specification 56.60-25(c).

The quantity of fuel stored may also be regulated. The 1978 U.S. National Electric Code, Section 700-6, calls for an on-site fuel supply capable of operating the prime mover at full demand load for at least two hours.

A large capacity storage tank is desirable to encourage bulk purchases and minimize dirt contamination. Maintaining a full tank minimizes condensation, particularly if the fuel is seldom used. It may be located either above or below ground level, but the high fuel level in any part of the system must not exceed the height of the injectors in the engine. This prevents any possibility of fuel leaking by the injectors into the cylinder.

The storage tank fill tube should be located for convenience and safety of the filling

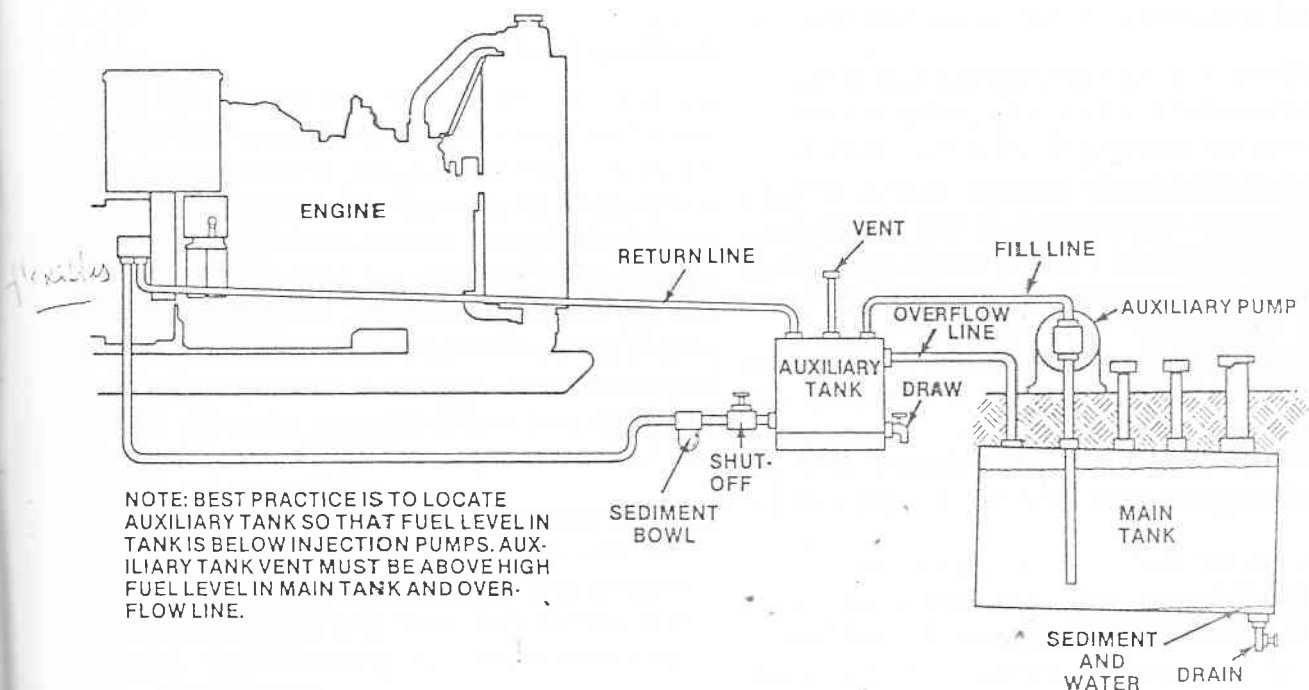


Figure 107

operation. A vent must be provided to relieve air pressure created by filling and prevent a vacuum as fuel is consumed.

A means of periodically drawing water and sediment from the tank must be provided. The tank bottom must be rounded and tilted about 2° to assure complete removal of these contaminants. Ground settling must also be taken into account when installing the tank to assure that the drain cock remains at the lowest level. In underground tanks, water may be removed by pumping through a tube placed down the fill pipe. Avoid seasonal settling by burying the tank below the frost line.

If a day tank is not used, the bulk tank must be located to provide a ready fuel supply to the engine-mounted transfer pump. The Caterpillar fuel pump is capable of priming from a 12 ft lift, but pipe size, bends, and cold ambients may modify this capability.

Copper-bearing steel tanks are preferred, but black iron tanks and fittings are satisfactory. Galvanized fittings or tanks should be avoided because of possible reactions with fuel impurities, clogging the fuel filter.

The delivery line for carrying the fuel to the engine-mounted fuel transfer pump and the return line for carrying excess fuel back to the tank should be no smaller in size than the fittings on the engine. If the distance from the fuel tank to the engine exceeds 30 ft (9.15 m) or if ambient temperature is extremely low, larger fuel supply and return lines should be used to ensure adequate flow.

The fuel line may be constructed from steel, black iron pipe, or from copper tub-

ing; galvanized pipe or any zinc-bearing alloy must not be used. The overflow line from the day tank (or, if no day tank is used, the fuel return line from the engine) should be of the same material and one size larger.

The return line should enter the top of the tank and contain no shutoff valves. Avoid dips in this line so that air may pass freely and prevent any vacuum in the fuel system. The fuel suction line should be positioned to remove fuel from a point about 2 in (5.1 cm) above the bottom and, if possible, at the opposite end of the tank in respect to the return line. If the fuel line enters the top of the tank, a pipe should be provided inside the tank to extend the line to the proper distance from the bottom. Joint cement which may be affected by fuel should not be in any part of the system. All connections should also be made without dependence in any way on gaskets. A length of flexible fuel line should be installed between the pipe from the fuel source (bulk storage or day tank) and the engine fuel inlet and return to prevent vibration damage to the pipes and fittings.

Auxiliary Tank

Auxiliary or "day tanks" are desirable if the main fuel tanks are located more than 50 ft (15.25 m) from the engine, or located above the engine or are more than 12 ft (3.65 m) below the engine. Total suction head should not exceed 12 ft (3.65 m). Although they will not aid the engine in fast starting, they do offer a convenient and ready storage of fuel. Day tanks also provide a settling reservoir so water and sediment can separate from the fuel.

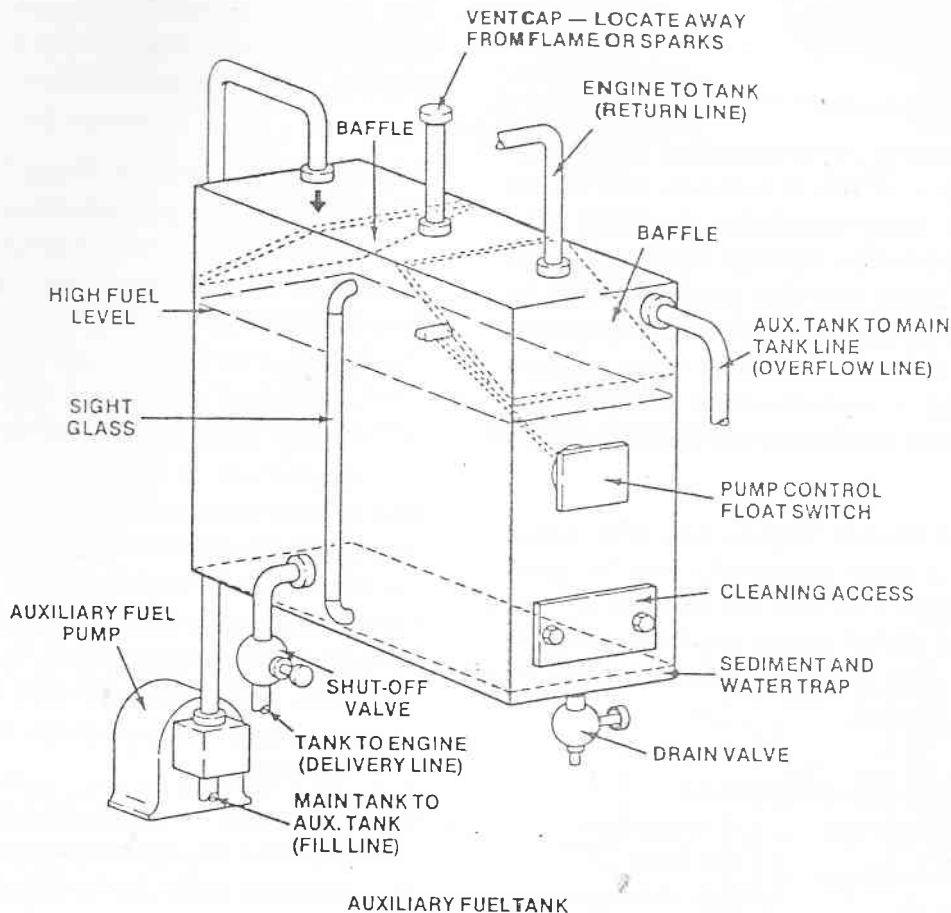


Figure 108

The auxiliary tank is located so that the level of the fuel is no higher than the fuel injection valves on the engine. The tank should be close enough to the engine to maintain total suction lift of less than 12 ft (3.65 m).

Filters

Clean fuel will assure maximum engine life and dependability. Anything less will endanger these characteristics. The engine filter protects the fuel injection pumps and nozzles. The incoming fuel must never bypass these filters.

Primary filters with 0.012 inch screens are available to extend the life of the engine

filter and the transfer pump. Water and sediment traps and filters can also be included upstream of the transfer pump, but pump performance must not be restricted.

In warm climates with large bulk storage, the diesel fuel may require full filtering every six months to a year. Every two years the fuel supply should be renewed to remove water, scale, and bacteria growth.

If it is necessary to store fuel for a longer time, kerosene may be substituted for diesel fuel. A simple engine power adjustment will be needed to account for this fuel's lower Btu content.

Fuel Selection

Engine Requirements

The fuel normally recommended for diesel generator sets is No. 2 furnace oil. When this fuel is also used for heating the building, a common storage tank for both the heating plant and the generator set is practical. In addition to reducing installation costs, this arrangement may reduce fuel costs as a consequence of quantity purchasing and eliminate fuel deterioration concerns.

A Caterpillar Diesel Engine has the capacity to burn a wide variety of fuels. In general, the engine can use the lowest priced distillate fuel which meets the following requirements (fuel condition as delivered to engine fuel filters):

Cetane Number (Precombustion Chamber Engines) 35 Minimum
Viscosity 100 SUS at 100° F Maximum
Pour Point 10° F (6° C) Below Ambient Temperature
Cloud Point Not Higher Than Ambient Temperature
Sulfur Adjust Oil Change Period For High Sulfur Fuel
Water and Sediment 0.1% Maximum

Some fuel specifications that meet the above requirements:

- ASTM D396 — No. 1 and No. 2 Fuels (Burner Fuels)
- ASTM D975 — No. 1-D and No. 2-D Diesel Fuel Oil
- BS2869 — Class A1, A2; B1, and B2-Engine Fuels
- BS2869 — Class C, C1, and C2 and Class D Burner Fuels
- DIN51601 — Diesel Fuel
- DIN51603 — EL Heating Oil

The following additional information describes certain characteristics and their relation to engine performance:

- A. Cetane Number — This index of ignition quality is determined in a special engine test by comparison with fuels used as standards for high and low cetane numbers.
- B. Sulfur — Since the advent of high detergent oils, sulfur content has become less critical. A limit of 0.4% maximum is used for Caterpillar Engines, without reducing oil change periods. Oil change periods are reduced with higher sulfur fuel.
- C. Gravity — The measurement is an index of the weight of a measured volume of fuel. Lower API ratings indicate heavier fuel which contain more heat value.
- D. Viscosity — This factor is a time measure to flow resistance of a fuel. Some low viscosity fuels are lubricants; a viscosity which is too high makes for poor fuel atomization thereby decreasing combustion efficiency.
- E. Distillation — This involves the heating of crude to relatively high temperatures. The vapor which results is drawn off at various temperature ranges, producing fuels of different types. The lighter fuel, such as gasoline, comes off first and the heavier fuel last.
- F. Flash Point — The lowest temperature at which the fuel will give off sufficient vapor to ignite momentarily when a flame is applied to the vapor.
- G. Pour Point — This denotes the lowest temperature at which fuel will flow or pour when chilled.
- H. Water and Sediment — The percentage by volume of water and foreign material which may be removed from fuel by centrifuging. No more than a trace should be present.

- I. Carbon Residue — Percentage by weight of dry carbon remaining when fuel is ignited and allowed to burn until no liquid remains.
- J. Ash — This is percentage by weight of dirt, dust, sand, and other foreign matter remaining after combustion.
- K. Corrosion — To determine corrosion, a polished copper strip is immersed in the fuel for three hours at 122° F (50° C). Any fuel imparting more than slight discoloration should be rejected.

API Gravity
 Viscosity at 100° F (37.78° C)
 Gasoline and Naptha Fraction
 Kerosene and Distillate Fraction
 Water and Sediment
 Cetane Number

45 Maximum
 100 SUS Maximum
 35% Maximum
 30% Minimum
 0.5% Maximum
 35 Minimum

Figure 109

The customer should order as heavy a fuel as his diesel engine and temperature conditions permit. Fuel costs can represent approximately 80% of total operating costs for an engine. It is good economics to look closely at the largest cost first.

NOTE: Caterpillar Diesel Engine fuel rack settings are based on 35° API (specific gravity) fuel. The use of fuel oil with a higher API (lower specific gravity) number will result in a reduction of power output. When using heavier fuels, a corrected rack setting should be used to ensure against power levels above the engines approved rating. Your Caterpillar Engine Dealer should be contacted to obtain the correct rack setting for fuels which do not comply with the recommendations. Operations above the approved engine horsepower rating level can result in reduced engine life, increased owning and operating costs, and customer dissatisfaction.

Crude Oil Fuels

Crude oil, in some cases, is a practical and economic fuel for diesel engines. Each crude oil must be evaluated individually, and special equipment may be needed to properly condition the fuel. Certain minimum guidelines have been established to determine the suitability of a crude.

Gaseous Fuels

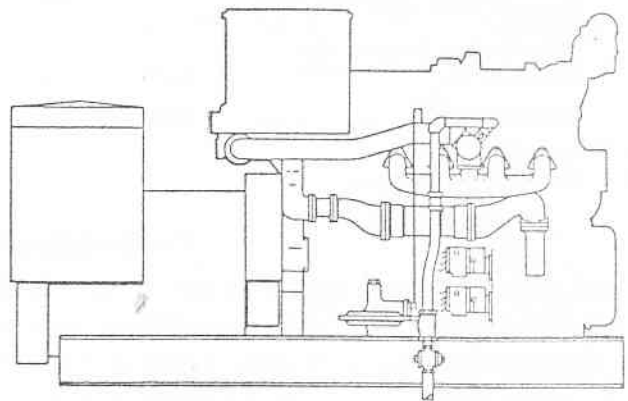


Figure 110

A wide variety of gaseous fuels can be burned in Caterpillar Gas Engines. Naturally aspirated (NA) engines usually require a minimum gas pressure of 2 psi (0.14 kg/cm²) to the gas regulator, while turbocharged units demand at least 12 psi (0.8 kg/cm²). These values may be lower only at low altitude installations where response to sudden load changes is not critical. The turbocharged engine also requires separate circuit aftercooling, so a 90° F (30° C) or 130° F (55° C) cooling source must be available. The following chart summarizes fuels commonly considered for generator sets:

FUEL SUMMARY

Fuel	Naturally Aspirated		Turbocharged-Aftercooled	
	High Compression Ratio	Low Compression Ratio	High Compression Ratio	Low Compression Ratio
Dry Processed Natural Gas	X	X	X (1)	X (2)
Propane	X (3 & 5)	X (3)	X (1, 3, 5)	X (2 & 3)
Butane		X (3)		
Natural Gas With Propane Air	X (3)	X (3)	X (1, 3, 4)	X (1 or 2 & 3)
Sewer Gas	X (6)		X (1 & 6)	X (2 & 6)
Natural Gas W/Hydrogen, Where:				
H ² Greater Than 50%	Not Recommended			
H ² = 50%		X (3)		
H ² = 30%	X (3)	X (3)		
H ² = 20%	X (3)	X (3)		X (1 & 3)
H ² = 10%	X (3)	X (3)	X (1 & 3)	X (1 & 3)
Field Gas		X (3)		X (2 & 3)

Notes:

- 1 — Temperature of water to aftercooler not to exceed 90° F (30° C).
- 2 — Temperature of water to aftercooler not to exceed 130° F (55° C).
- 3 — Retarded timing required.
- 4 — The propane air added should not exceed 35% of the mixture volume.
- 5 — For nonlug applications only.
- 6 — Advanced timing and horsepower derating required.

Figure 111

The footnotes indicate the adjustments necessary to achieve optimum performance. In some cases, various gases can be used as a backup for the primary fuel Figure 112. The addition of another regulator and a change of carburetor may be necessary to accommodate the particular gas.

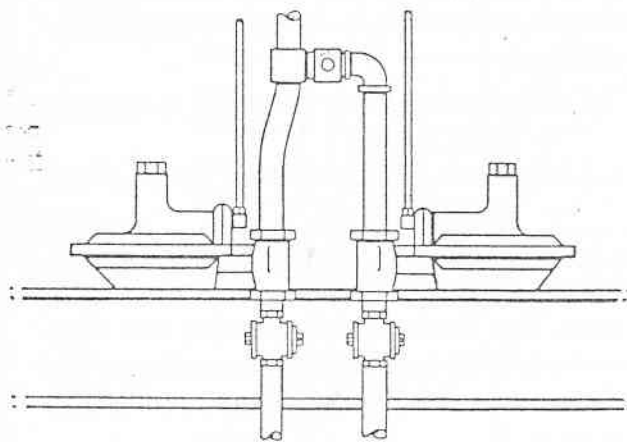


Figure 112

STARTING SYSTEMS

Several starting mediums are available, but the two most common are electric (DC) and air. They are easily controlled and can be applied either manually or automatically.

Startability of a diesel engine is affected primarily by ambient temperature and lubricating oil viscosity. The diesel relies on the heat of compression to ignite the fuel. This heat is a result of both the cranking speed and the length of time for cranking. When the engine is cold, a longer period of cranking is required to develop this ignition temperature.

Heavy oil imposes the greatest load on the cranking motor. Both the type of oil and the temperature can drastically alter its viscos-

ity. An SAE 30 oil will, for example, approach the consistency of grease at temperatures below 32° F (0° C).

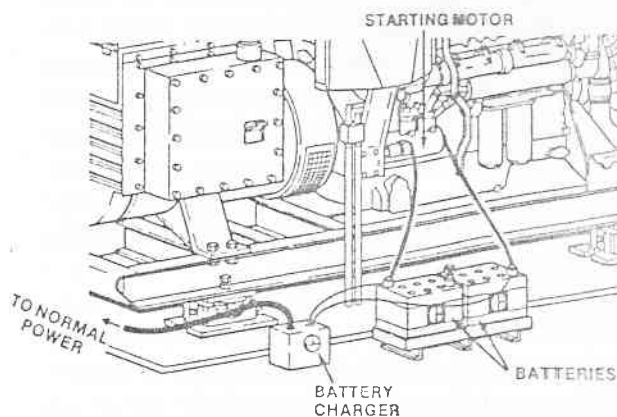


Figure 113

Electric Start

Electric motors utilize low voltage DC power and provide fast, convenient, push-button starting with relatively lightweight, compact engine-mounted components. A motor contractor is included in the system to relieve the control logic circuits of high cranking currents.

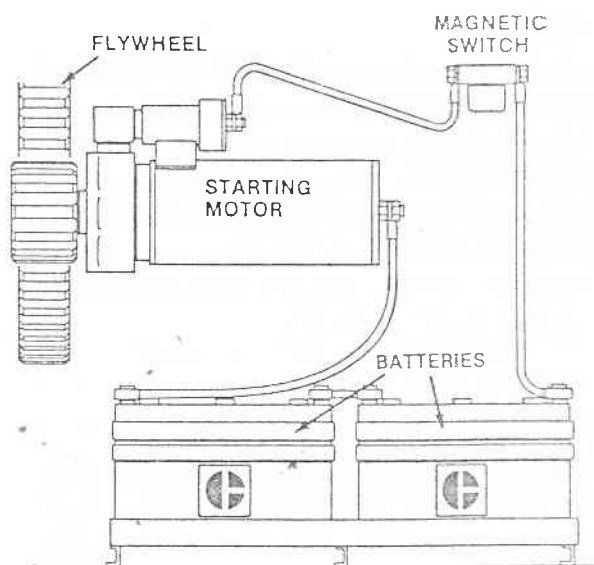


Figure 114

Batteries

The battery must provide sufficient power to crank the engine long and fast enough to start. Lead-acid types are most common, have high output capabilities, and have the lowest first cost. Nickel-cadmium batteries are more costly, but exhibit long shelf life and require a minimum of maintenance. Because the nickel-cadmium type is designed for long life, they may incorporate a thick-plate design which can decrease their high discharge capability. The battery supplier must be consulted for specific application recommendations.

Ambient temperatures drastically affect battery performance and charging efficiencies. They should be warmed to 90° F (32° C) maximum temperature to assure rated output is achieved. The impact of colder temperatures is described below:

Temperature Vs Output		
°F	°C	Percent of 80° F (27° C) Ampere Hours Output Rating
80	27	100
32	0	65
0	- 18	40

Figure 115

The cranking batteries should be located for easy visual inspection and maintenance, away from a flame or spark source, and isolated from vibration. They must be mounted level and protected from splash and dirt. To encourage short cable lengths and minimize voltage drops, locate the batteries close to the starting motor.

Cable Size

Both the start circuit between battery and starting motor and the control circuit between battery, switch, and motor solenoid must be within maximum resistance limits shown.

MAXIMUM ALLOWABLE RESISTANCE

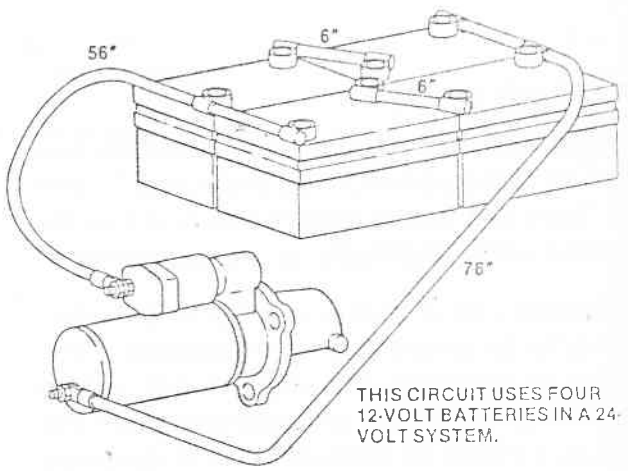
Magnetic Switch & Series-Parallel Circuit	Solenoid Switch Circuit	Starting Motor Circuit
12-Volt System, 0.048 ohm	0.0067 ohm	0.0012 ohm
24-Volt System, 0.10 ohm	0.030 ohm	0.002 ohm
32-Volt System, 0.124 ohm	0.070 ohm	0.002 ohm

Not all of this resistance is allowed for cables. Connections and contactors, except the motor solenoid contactor, must also be included in the total allowable resistance. Additional fixed resistance allowances are:

- Contactors (relays, solenoid, switches)
— 0.0002 ohm.
- Connections (each series connectors)
— 0.00001 ohm.

The fixed resistance, connections, and contactors can be determined by the cable routing. The fixed resistance (R_f) can then be subtracted from the total resistance (R_t) to find the allowable cable resistance (R_c). $R_t - R_f = R_c$.

Example:



SYSTEM	24-volt
STARTING MOTOR TYPE	HEAVY DUTY
MAXIMUM ALLOWABLE RESISTANCE	.00200
MINUS FIXED RESISTANCE—	
6 CONNECTIONS @ .00001	.00006 OHM
RESISTANCE REMAINING FOR CABLE	.00194
BATTERY CABLE LENGTH	144"

Figure 116

With cable length and fixed resistance determined, cable size can now be selected by using the following charts: **Only full-stranded copper wire should be used.**

Cable Length and Resistance

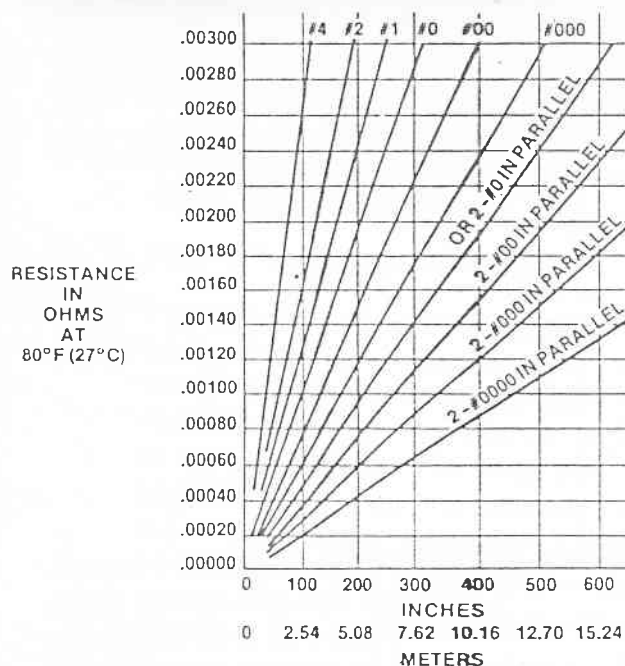


Figure 117

To meet cable length and resistance requirements, **cable size must be No. 1.** (For ease in determining fixed resistance in a parallel circuit, only series connections in one leg of the parallel circuit are counted.)

Battery Charger

Various types of chargers are available to replenish a battery's energy. Trickle chargers are designed for continuous service on

float batteries and automatically shut down to milliamperes current when the battery is fully charged.

Float-charge chargers are generally more expensive than trickle chargers and are used in applications which demand maximum battery life. These chargers can include line and load regulation and current limiting devices which permit carrying continuous loads up to their rated output.

Any type of battery charger used must be capable of limiting peak currents during the cranking cycle or have a relay to disconnect the battery charger during the cranking cycle. In applications where an engine-driven alternator and the battery charger are both used, the disconnect relay is usually controlled to disconnect the battery charger during cranking and running periods of the engine.

Engine-driven generators or alternators can be used, but they have the disadvantage of charging batteries only while the engine is running. In cases, especially standby applications, where the generator set could be subject to many starts during intermittent utility failure, insufficient battery capacity could cause problems.

Air Starting Systems

Air starting, either manual or automatic, is a highly reliable method of starting. The torque available from an air motor will accelerate the engine to twice the cranking speed in about half the time required by an electric starter.

Compressed air from a 110-250 psi (759-1725 kPa) source is regulated to a 110 psi (759 kPa) level and delivered to the air motor. The pressure air source may be both from an air receiver and a plant air supply.

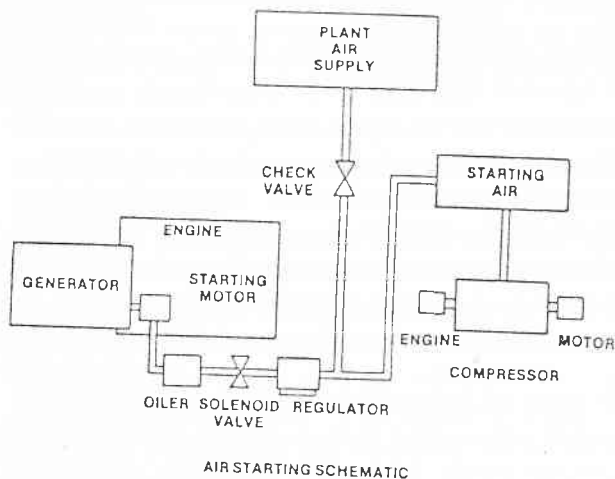


Figure 118

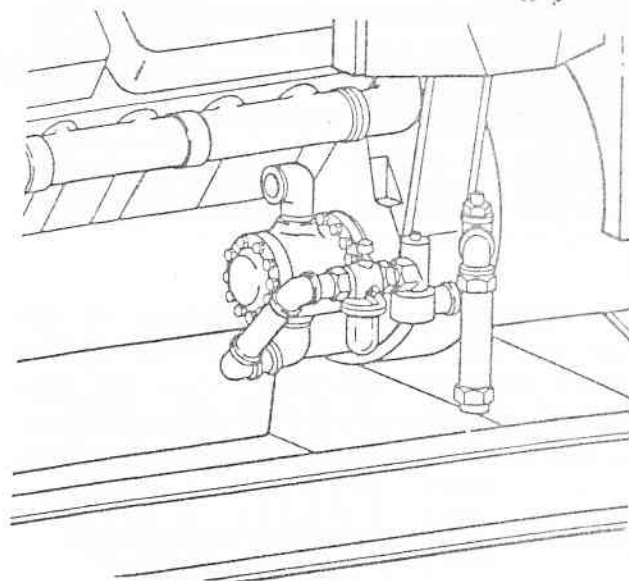


Figure 119

A check valve between the plant air source and receiver will assure that a failure of plant air will not deplete the backup supply. The generator set compressor is usually driven both by an electric motor and a gasoline engine. The electric motor should be wired to the emergency power source to allow operation under all conditions.

On tandem or compound engines where two motors and solenoid valves are used, the valves must be equal distance from their respective motors. When a single solenoid controls air to both motors, piping between the valve and motors must also be of equal length.

The air discharge pipe should be short and direct, and at least of equal size as the discharge opening of the air receiver. Black iron pipe is preferable and must be supported to avoid stresses on the compressor cylinder head and manifold. Flexible connections between the compressor outlet and the piping are required.

Deposits of oil-water mixture which accumulate in the receiver and piping can be removed by traps installed at intervals in the lines. Lines should be sloped toward these traps.

Air receivers specified should meet ASME specifications and be equipped with a safety valve and gauge. Safety valves should be checked frequently to guard against possible sticking.

Many applications require sizing receivers to provide a specified number of starts. This can be accomplished by using this equation:

$$N_s = \frac{R_c \times (R_p - 90)}{A_r \times A_p}$$

N_s = Number of starts

R_c = Receiver capacity (ft³) (m³)

R_p = Receiver pressure (psia) (kPa)

A_r = Air requirement per start (ft³) (m³)

A_p = Atmospheric pressure (psia) (kPa)

90 = Psia minimum (724 kPa)

The quantity of free air required per start (Ar) depends on three factors:

1. Length of time required per start.

The length of time per start depends upon the engine model, condition, ambient air temperature, oil viscosity, fuel type, condition of fuel system, and design cranking speed. Five to seven seconds is typical for a diesel engine at 80° F (25° C). Restarts of a hot engine normally take less than two seconds. Due to the time necessary to develop a combustible mixture in the intake manifold, gas engines usually exhibit cold starting times up to double that of a diesel.

2. Rate of free air consumption.

The rate of free air consumption depends to some extent on these same variables and also on the pressure regulator setting. The correct setting is 90-100 psi (620-758 kPa) with the higher pressure used to improve starting under adverse conditions. 5 ft³/s to 15 ft³/s (0.14 m³/s to 0.42 m³/s) is typical for engines from 50 hp to 1200 hp (37 kW to 895 kW).

3. Promptness of operator shutting off air supply as soon as engine starts or the sensing system closing the solenoid air valve.

Air cranking systems are prone to freezing at low ambients. Water vapor in the compressed air supply will freeze as the air is expanded below 32° F (0° C). A dryer at the compressor outlet or a small quantity of alcohol in the starter air tank is required. Below 0° F (-18° C) consult the generator set supplier.

Starting Aids

Starting aids are recommended for temperatures below 70° F (20° C) to reduce cranking time.

Jacket Water Heaters

One of the most common starting aids, especially for emergency generator sets, is a jacket water heater. It is used on both manual and automatic systems. Jacket water heaters are normally recommended for ambient air temperature below 70° F (20° C) and are essential for all automatic start installations. The jacket water heater preconditions the engine for quick starting by maintaining jacket water temperature during shutdown periods. Particular attention should be paid to Vee-type engines to ensure proper circulation in the engine block (under the regulators). Water temperature in the heater must be controlled by a thermostat.

The proper heater for a particular installation should maintain jacket water temperature near 90° F (30° C), considering ambient temperature, wind, exposure to the elements, etc.

Glow Plugs

One method for bringing air-fuel mixture up to auto ignition temperature for starting is to preheat the combustion chambers. This starting method is particularly applicable to manual start installations and is easily accomplished on precombustion-type engines by installing a resistance-type glow plug in each precombustion chamber. Direct injection engines cannot accommodate glow plugs. When current is applied, the plug tip reaches a temperature of 1800° F (980° C) in approximately 30 seconds. This vaporizes the incoming fuel and decreases the time required to start the diesel engine in cold weather.

Flame Start

This system is usually used with manual starting and consists of one or two flame glow plugs projecting into the air inlet manifold. A small amount of diesel fuel is ignited during starting and maintained until smooth idling conditions are achieved.

Ether

Ether starting aids are restricted to manual starting systems and are rarely used for generator set applications. Ether assists starting because it is a highly volatile fluid with a low ignition point. When ether is introduced into the diesel air-fuel mixture, compression ignition will occur at reduced temperatures. The high pressure capsule method appears to be the safest and most positive system for ether injection.

Oil Heaters

Heating elements in direct contact with lubricating oil are usually not recommended due to the danger of oil coking. To avoid this condition, heater skin temperatures should not exceed 300° F (150° C) and have a maximum heat density of 8 W/in².

ALTITUDE/TEMPERATURE CONSIDERATIONS

Extremes in climate require a careful analysis of the impact on the generator set. Because both altitude or barometric pressure and temperature have a direct relationship with air density, they must be considered jointly. Refer to the specific sections in this guidebook for detailed information of the following equipment:

Engine combustion air may be decreased by high temperatures and altitudes. Turbo-charged engines can tolerate an amount of these conditions, but the capabilities of each engine must be reviewed. High altitudes generally promote low temperatures, so engine power derations may possibly be avoided by routing the cool outside air directly to the engine air cleaners. However, when automatic starting is applied, the combination of high altitude and cold air may cause the engine to over-fuel and have difficulty in coming up to operating speed. Factory consultation should be sought for units started automatically above 8,000 ft (2400 m).

Radiators may be adversely affected on both the water and air side. Cold temperatures require antifreeze, which decreases the radiator's performance during warm weather operation. High altitudes also cause deration of radiator.

Jacket water heaters aid in start-up and are usually a necessity in automatic starting applications. Thermostatically controlled radiator shutters should be considered to encourage warm engine room operation.

Severe cold of -20° F to -65° F (-30° C to -55° C) demands special artic lubricating oils and greases. Engine oil may conform to MIL-L 10295 while MIL-G 23827 grease may be specified.

Specifications on all V-belts, hoses, wiring, and other rubber products should be reviewed to determine if they will withstand extreme cold. Military specification MIL-W 5086 should be used as a guide.

Battery performance is dramatically reduced in cold weather. The total battery capacity of a system must be increased at least three times to approach normal temperature performance. Warm air or electric resistor strips are used to maintain appropriate temperatures as well as coil heaters utilizing engine coolant. Heating with the diesel engine exhaust is not recommended due to the contaminants in the exhaust.

Hydraulic or gasoline engine starting may be practical in specific installations. Hydraulic systems provide high torque at relatively high speeds which encourage starting. They are completely sealed and not susceptible to moisture from condensation. Gasoline starting engines readily start in cold weather but cannot be used in automatic starting applications.

EQUIPMENT MAINTENANCE

Scheduled maintenance for an on-site power plant will vary, depending on equipment configuration and duration of use. Maintenance

procedures for equipment in continuous use is well documented and can be obtained from the suppliers of the equipment. Requirements for emergency or standby generator sets are not so well defined, particularly for the diesel engine. The Caterpillar Dealer can develop an operation and maintenance schedule to satisfy each installation.

The best method to assure the reliability of an emergency system is to periodically test the entire system. A simulated power failure should be conducted monthly, with actual transfer switch operation to connect the full emergency power demand to the generator set. The emergency system should function for one hour in the presence of an authorized mechanic.

After completion of the run, the system should be readied for automatic operation and rechecks of fuel level and battery condition should be made.

It is recognized that the above schedule may not be practical for a particular in-

stallation. However, certain minimum testing procedures may be required by national or local codes and legislation. NFPA No. 76A (1973), Section 921 states:

"Generator sets serving emergency and equipment systems shall be inspected daily and shall be exercised for at least 30 minutes under load conditions at intervals of not more than seven days. The 30-minute exercise period is an absolute minimum and the individual engine manufacturer's recommendation shall be followed."

If a specification calls for a weekly startup and no load is available, a running time of 5-30 minutes is suggested. Further operation will be of no value. This test should be complemented annually by at least a 1-hour run with 30% of rated load. An authorized operator should be present for the weekly startup, while the annual test should be conducted by an authorized mechanic.

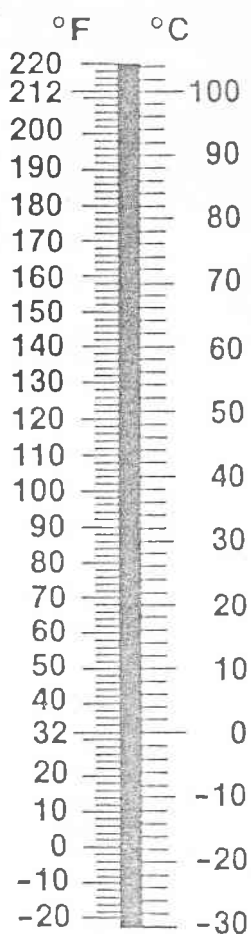
ENGLISH TO METRIC CONVERSION FACTORS

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
BTU	BRITISH THERMAL UNIT	1055.0	JOULE	J
BTU/HP-HR	BRITISH THERMAL UNIT/ HORSEPOWER-HOUR	0.001 415	MEGAJOULES/KILOWATT- HOUR	MJ/KW-HR
BTU/HR	BRITISH THERMAL UNIT/ HOUR	1055.0	JOULES/HOUR	J/HR
BTU/MIN	BRITISH THERMAL UNIT MINUTE	0.017 584	KILOWATT	KW
°C	CELSIUS (DEGREES)	[(1.8 C) + 32]	FAHRENHEIT (DEGREES)	°F
CU FT	CUBIC FEET	0.0283	CUBIC METER	M ³
CU FT/HR	CUBIC FEET/HOUR	0.0283	CUBIC METER/HOUR	M ³ /HR
CFM	CUBIC FEET/MINUTE	0.0283	CUBIC METER/MINUTE	M ³ /MIN
CU IN	CUBIC INCH	0.016 387 1	LITER	L
CU IN	CUBIC INCH	0.000 016 387 1	CUBIC METER	M ³
°F	FAHRENHEIT (DEGREES)	[0.5555 (F-32)]	CELSIUS (DEGREES)	°C
FT/MIN	FEET/MINUTE	0.3048	METER/MINUTE	M/MIN
FT	FEET	0.3048	METER	M
FT H ₂ O	FEET OF WATER	2.986 08	KILOPASCAL	KPA
GPH	GALLON/HOUR	3.7854	LITER/HOUR	L/HR
GPM	GALLON/MINUTE	3.7854	LITER/MINUTE	L/MIN
HP	HORSEPOWER	0.7457	KILOWATT	KW
IN HG	INCH OF MERCURY	3.3768	KILOPASCAL	KPA
IN	INCH	25.4	MILLIMETER	MM
IN H ₂ O	INCH OF WATER	0.248 84	KILOPASCAL	KPA
KW	KILOWATT	56.869 88	BRITISH THERMAL UNIT/MINUTE	BTU/MIN
L	LITER	61.0236	CUBIC INCH	CU IN
μ	MICRON	1.0	MICROMETER	μM
LB	POUND	0.4536	KILOGRAM (MASS)	KG
LB	POUND	4.448 22	NEWTON (FORCE)	N
LB FT (FT-LB)	POUND FOOT	1.355 818	NEWTON METER	N•M
LB IN (IN-LB)	POUND INCH	0.112 985	NEWTON METER	N•M
LB/IN	POUNDS/INCH	0.175 126 8	NEWTON/MILLIMETER	N/MM
LB/IN	POUNDS/INCH	175.1268	NEWTON/METER	N/M
LB/HP-HR	POUND/HORSEPOWER-HOUR	608.28	GRAM/KILOWATT HOUR	G/KW-HR
LB/HR	POUND/HOUR	453.6	GRAM/HOUR	G/HR
M ³	CUBIC METER	61 023.61	CUBIC INCH	CU IN
PSI	POUNDS/SQUARE INCH	6.894 75	KILOPASCAL	KPA
QT	QUART	0.946 35	LITER	L
SQ FT	SQUARE FEET	0.0929	SQUARE METER	M ²
SQ IN	SQUARE INCH	6.4516	SQUARE CENTIMETER	CM ²
U.S. GAL	U.S. GALLON	3.7854	LITER	L

LENGTH EQUIVALENTS

UNIT	CENTIMETERS	INCHES	FEET	YARDS	METERS	KILOMETERS	MILES
1 CENTIMETER	1	0.3937	0.03281	0.01094	0.01	—	—
1 INCH	2.540	1	0.08333	0.02778	0.0254	—	—
1 FOOT	30.48	12	1	0.3333	0.3048	—	—
1 YARD	91.44	36	3	1	0.9144	—	—
1 METER	100	39.37	3.281	1.0936	1	—	—
1 KILOMETER	100,000	39,370	3,281	1093.6	1000	1	0.6214
1 MILE	160,935	63,360	5,280	1,760	1,609	1.609	1

TEMPERATURE CONVERSION



VOLUME AND CAPACITY EQUIVALENTS

UNIT	CU. IN.	CU. FT.	CU. YD.	CU. CM	CU. M	U.S. LIQUID GALLONS	IMPERIAL GALLONS	LITERS
1 CU. IN.	1	.000579	.0000214	16.39	.0000164	.004329	.00359	.0164
1 CU. FT.	1728	1	.03704	28,317	.028	7.481	6.23	28.32
1 CU. YD.	46,656	27	1	764,600	.765	202	167.9	764.6
1 CU. CM	.061	.0000353	.00000131	1	.000001	.000264	.00022	.001
1 CU. M	61,020	35.31	1.308	1,000,000	1	264.2	220.2	1000
1 U.S. LIQUID GAL.	231	.1337	.00495	3785	.003785	1	.833	3.785
1 IMPERIAL GAL.	277.42	.16	.00594	4545.6	.004546	1.2	1	4.546
1 LITER	61.02	.03531	.001308	1000	.001	.2642	.22	1
1 ACRE FT.	—	43,560	1613.33	—	1233.5	325,850	271,335	—

(There is no standard liquid barrel; by trade custom, 1 BBL. of petroleum oil, unrefined — 42 gallons)

UNITS OF PRESSURE AND HEAD

UNIT	MM HG (0° C)	IN. HG (0° C)	IN. WATER (39° F)	FT. WATER (39° F)
MM HG	1	0.03937	0.53526	0.0446
IN. HG	25.4	1	13.5955	1.13296
IN. WATER	1.86827	0.07355	1	0.08333
FT. WATER	22.4192	0.88265	12	1
LBS. PER SQ. IN.	51.7149	2.03602	27.6807	2.3067
KILOGRAMS PER SQ. CM	735.559	28.959	393.71171	32.80931
BAR	750.062	29.530	401.4742	33.45618
ATMOSPHERES	760	29.9213	406.79375	33.89948
KILO PASCAL	7.500 62	.295 30	4.014 742	.334 5618

	PSI LB PER SQ. IN.	KILOGRAMS PER SQ. IN. CM	BAR	ATMOSPHERES (14.7 PSI)	KILO PASCAL
MM HG	0.01934	0.00136	0.00133	0.001315	—
IN. HG	0.49115	0.03453	0.03386	0.03342	—
IN. WATER	0.03613	0.00254	0.00249	0.00246	0.249
FT. WATER	0.43352	0.030479	0.02989	0.02950	2.989
LBS. PER SQ. IN.	1	0.07031	0.06895	0.06805	6.895
KILOGRAMS PER SQ. CM	14.2233	1	0.98067	0.96784	98.067
BAR	14.504	1.01972	1	0.98692	100.
ATMOSPHERES	14.6959	1.03323	1.01325	1	101.325
KILO PASCAL	0.145 038	0.010.1972	0.010000	0.009.86.920	1

GENERATOR RATING

3 PHASE AMPERES — 80% POWER FACTOR

KVA	KW	208V	220V	240V	380V	400V	440V	450V	480V	600V	2400V	3300V	4160V
6.3	5	17.5	16.5	15.2	9.6	9.1	8.3	8.1	7.6	6.1			
9.4	7.5	26.1	24.7	22.6	14.3	13.6	12.3	12	11.3	9.1			
12.5	10	34.7	33	30.1	19.2	18.2	16.6	16.2	15.1	12			
18.7	15	52	49.5	45	28.8	27.3	24.9	24.4	22.5	18			
25	20	69.5	66	60.2	38.4	36.4	33.2	32.4	30.1	24	6	4.4	3.5
31.3	25	87	82.5	75.5	48	45.5	41.5	40.5	37.8	30	7.5	5.5	4.4
37.5	30	104	99	90.3	57.6	54.6	49.8	48.7	45.2	36	9.1	6.6	5.2
50	40	139	132	120	77	73	66.5	65	60	48	12.1	8.8	7
62.5	50	173	165	152	96	91	83	81	76	61	15.1	10.9	8.7
75	60	208	198	181	115	109	99.6	97.5	91	72	18.1	13.1	10.5
93.8	75	261	247	226	143	136	123	120	113	90	22.6	16.4	13
100	80	278	264	240	154	146	133	130	120	96	24.1	17.6	13.9
125	100	347	330	301	192	182	166	162	150	120	30	21.8	17.5
156	125	433	413	375	240	228	208	204	188	150	38	27.3	22
187	150	520	495	450	288	273	249	244	225	180	45	33	26
219	175	608	577	527	335	318	289	283	264	211	53	38	31
250	200	694	660	601	384	364	332	324	301	241	60	44	35
312	250	866	825	751	480	455	415	405	376	300	75	55	43
375	300	1040	990	903	576	546	498	487	451	361	90	66	52
438	350	1220	1155	1053	672	637	581	568	527	422	105	77	61
500	400	1390	1320	1203	770	730	665	650	602	481	120	88	69
625	500	1735	1650	1504	960	910	830	810	752	602	150	109	87
750	600	2080	1980	1803	1150	1090	996	975	902	721	180	131	104
875	700	2430	2310	2104	1344	1274	1162	1136	1052	842	210	153	121
1000	800	2780	2640	2405	1540	1460	1330	1300	1203	962	241	176	139
1125	900	3120	2970	2709	1730	1640	1495	1460	1354	1082	271	197	156
1250	1000	3470	3300	3009	1920	1820	1660	1620	1504	1202	301	218	174
1563	1250	4350	4130	3765	2400	2280	2080	2040	1885	1503	376	273	218
1875	1500	5205	4950	4520	2880	2730	2490	2440	2260	1805	452	327	261
2188	1750			5280	3350	3180	2890	2830	2640	2106	528	380	304
2500	2000			6020	3840	3640	3320	3240	3015	2405	602	436	348
2812	2250			6780	4320	4095	3735	3645	3400	2710	678	491	392
3125	2500			7520	4800	4560	4160	4080	3765	3005	752	546	435
3750	3000			9040	5760	5460	4980	4880	4525	3610	904	654	522
4375	3500			10550	6700	6360	5780	5660	5285	4220	1055	760	610
5000	4000			12040	7680	7280	6640	6480	6035	4810	1204	872	695

CONVERSION TABLES

UNITS OF POWER

Mechanical power and ratings of motors and engines are expressed in Horsepower.
Electrical power is commonly expressed in watts or kilowatts.

Unit	Horsepower	Foot Lb per Minute	Watts	Kilowatts	Metric Horsepower	BTU per Minute
1 Horsepower	1	33.000	746	.746	1.014	42.4
1 Foot Lb per Minute	—	1	.0226	—	—	.001285
1 Watt	.00134	14.2	1	.001	.00136	.0568
1 Kilowatt	1.344	14.250	4.000	1	1.360	56.8
1 Metric Horsepower	0.86	32.550	7.36	.736	1	41.8
1 BTU per Minute	0.236	778	17.6	0.176	0.239	1

MISCELLANEOUS EQUIVALENTS

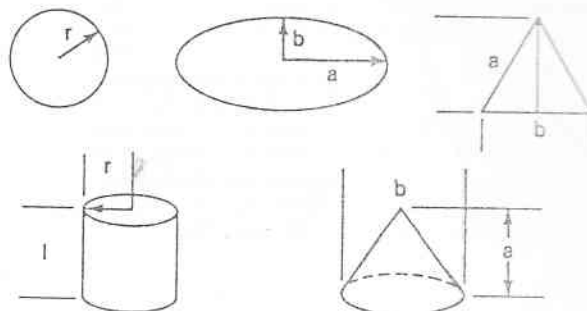
1 BTU = Heat required to raise 1 lb. water 1° F = 778 ft. lb.
.000292 KW-hr. = .252 KG-eal. = 0.0039 HP-hr.

1 HP = 746 watts = 33,000 ft. lb. per min. = 550 ft. lb. per sec. = 42.4 BTU per min. = 1.914 metric HP.

1 KW = 1000 watts = 1.341 HP, = 3413 BTU per hr.

1 HP-hr. = 2544 BTU

GEOMETRIC FORMULAS



BRAKE MEAN EFFECTIVE PRESSURE:

$$\text{BMEP psi (4-cycle)} = \frac{792,000 \times \text{BHP}}{\text{RPM} \times \text{Displacement}}$$

$$\text{BMEP psi (2-cycle)} = \frac{396,000 \times \text{BHP}}{\text{RPM} \times \text{Displacement}}$$

$$\text{BMEP} = \frac{150.8 \times \text{Torque}}{\text{Displacement}}$$

TORQUE:

$$T \text{ in lb. ft.} = \frac{\text{Displacement} \times \text{BMEP}}{150.8}$$

$$T \text{ in lb. ft.} = \frac{33000 \times \text{BHP}}{2\pi \times \text{RPM}} = \frac{5252 \times \text{BHP}}{\text{RPM}}$$

Circumference: Circle $2\pi r$

Area: Circle πr^2
Ellipse πab
Sphere $4\pi r^2$
Cylinder $2\pi r(r + l)$
Triangle $\frac{1}{2}ab$

Volume: Ellipsoid of revolution $\frac{4}{3}\pi b^2 a$
Sphere $\frac{4}{3}\pi r^3$
Cylinder $\pi r^2 l$
Cone $\frac{\pi b^2 a}{12}$

Analytical: Circle $\frac{x^2}{r^2} + \frac{y^2}{r^2} = 1$

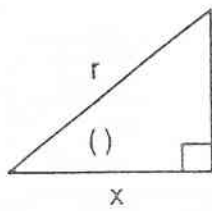
Ellipse $\frac{x^2}{a^2} + \frac{y^2}{b^2} = 1$

Hyperbola $\frac{x^2}{a^2} - \frac{y^2}{b^2} = 1$

Parabola $y^2 = \pm 2px$
Line $y = mx + b$

MATHEMATICAL EXPRESSIONS

Trigonometric Relations



$$\sin O = \frac{y}{r}$$

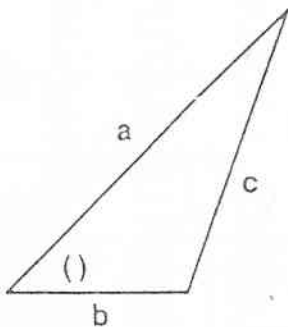
$$\cos O = \frac{x}{r}$$

$$\tan O = \frac{y}{x}$$

$$\sin^2 O + \cos^2 O = 1$$

$$e^{in} = \cos O + i \sin O \quad i = \sqrt{-1}$$

Law of Cosines



$$a^2 + b^2 - 2ab \cos O = c^2$$

RULES OF THUMB

Laws of Exponents

$$a^x \times a^y = a^{x+y} \quad \frac{1}{a^x} = a^{-x}$$

$$(ab)^x = a^x \times b^x \quad \frac{a^x}{a^y} = a^{x-y}$$

$$(a^x)^y = a^{xy} \quad a^0 = 1$$

Laws of Logarithms

$$\ln(y^x) = x \ln y$$

$$\ln(ab) = \ln a + \ln b$$

$$\ln\left(\frac{a}{b}\right) = \ln a - \ln b$$

HEAT REJECTION:

% of Fuel Energy Consumed

BHP	30%
Jacket Water	30%
Exhaust	30%
Radiation	10%

Jacket Water

Turbocharged Engines

$$\text{BTU/min.} = 42 \times \text{BHP}$$

Naturally-Aspirated, Roots Blown and Spark-Ignited Engines

$$\text{BTU/min.} = 45 \times \text{BHP}$$

Oil Cooler BTU/min. = 5 × BHP

Watercooled Manifold BTU/min. = 7 × BHP

Torque Converter BTU/min. = 42.4 × BHP input × (100 - conv. eff.)

100

FUEL CONSUMPTION — BHP:

$$\text{BHP} = \text{GPH fuel} \times 15$$

Diesel

1/15 gal. per BHP-Hr.

$$\text{BHP} = \text{GPH fuel} \times 9.5$$

Gasoline

1/10 gal. per BHP-Hr.

$$\text{BHP} = \text{Cu. Ft./Hr. fuel} \times 1/8$$

Natural Gas*

7 to 8 cu. ft. per BHP-Hr.

$$\text{KW} = \text{GPH fuel} \times 10$$

Diesel

1/10 gal. per KW-Hr.

*100 BTU gas.

GAS COMPRESSOR:

$$\text{BHP} = 22 \text{ RcVS}$$

Where: Rc = Stage Compression Ratio

V = Million cu. ft./day

S = Number of Stages

COOLING:

Heat Exchanger Flow Rate

Raw water to jacket water 1:1 to 2:1

Submerged Pipe Cooling

1/2 sq. ft. surface area per HP

With 85° F flowing water

ELECTRICITY:

Generator Capacity Required

Motors:

1 KW per nameplate HP (motor running cool or warm to touch)

1 1/4 KW per nameplate HP (motor running hot to touch)

Horsepower Requirements

$$1 1/2 \text{ BHP per KW of load or } \frac{\text{KW}}{0.746 \times \text{Gen. Eff.}}$$

ELECTRIC SETS:

Motor Starting Requirements

Inrush KVA (Code F motor) = 5.5 × BHP

Inrush Current (Code F motor) = 6.2 × Full load rated current

1 KVA per HP at full load

Generator full load rated current capacity

Voltage	Rated Current
120	6.01 × KW
208	3.47 × KW
240	3.01 × KW
480	1.50 × KW
2400	0.30 × KW
4160	0.17 × KW

Generator Cooling Requirements

Air Flow = 20 CFM per KW

Circuit Breaker Trip Selection

1.15 to 1.25 × full load generator amp rating

Single Phase Rating of 3-Phase Generator

60% of 3-phase rating

Generator Temperature Rise

Increase 1° C for each 330 feet above 3300 feet

ON SITE POWER REQUIREMENTS:

Based on 100,000 sq. ft. of office bldg., etc., and 40° N. latitudes

Electric Requirements:

600 kW continuous load
(Air conditioning is absorption)
Use three - 300 KW units
(2 prime and 1 standby)

Air Conditioning Compressor:

400 tons prime load
Use two - 200 HP engines
(No standby)

REFRIGERATION:

One ton refrigeration = 200 BTU/Min. = 12,000 BTU/Hr.

One boiler HP = 33,475 BTU/Hr.

One ton compressor rating = One Engine HP

Auxiliary air conditioning equipment requires

14 HP per ton of compressor rating

Ice Plant:

Ice plant power requires 4-5 HP per daily ton capacity

AIR COMPRESSORS:

HP = $\frac{1}{4} \times$ cu. ft. per minute at 100 psi

Increase BHP 10% for 125 psi

Decrease BHP 10% for 80 psi

CONVEYORS: 15 to 20° Incline.

$$\text{BHP} = \frac{\text{Vertical lift in feet} \times \text{tons per hour}}{500}$$

PUMPS:

$$\text{Deep Well BHP} = \frac{\text{Feet of lift per 1000 GPM}}{3}$$

$$\text{Pipe Line BHP} = \text{Barrels per hour} \times \text{psi} \times 0.00053$$

$$\text{Any Liquid BHP} = \frac{\text{GPM} \times \text{lb./gal. (Liquid)} \times \text{feet of head}}{33,000 \times \text{pump efficiency}^*}$$

*Efficiency: Centrifugal

Single impeller, double suction 65-80%

Single impeller, side suction 55-75%

Deep well turbine 65-80%

Reciprocating 75%

OILFIELD DRILLING:

Hoisting

$$\text{BHP} = \frac{\text{Weight} \times \text{FPM (assume 100 is unknown)}}{33,000 \times 0.85 \text{ (eff.)}}$$

Mud Pumps

$$\text{BHP} = \frac{\text{GPM} \times \text{lb./gal.} \times \text{(feet of head)}}{33,000 \times \text{pump efficiency (see pumps)}}$$

Dry Table

Depth in feet	BHP Required
0 - 4000	75
4000 - 8000	100
8000 - 12000	150
12000 - 16000	200

SAWMILL:

1½ BHP per inch of saw diameter at 500 RPM

Increase or decrease in proportion to RPM

Swing Cut-Off Saw

24-inch 3 BHP

36-inch 7½ BHP

42-inch 10 BHP

Table Trimmer 7½ to 10 BHP

Blower Fan, 12-foot sawdust 3 to 5 BHP

Planer Mill 2 to 4 BHP per 100 board feet per hour

24 to 30-inch planers 15 to 25 BHP

Edgers

2 saws 12 to 15 BHP

3 saws 15 to 25 BHP

Slab Saw 10 BHP

Jack Ladder 10 BHP

Approximate fuel consumption

Softwood 1 gal. per 1000 board feet

Hardwood 1 gal. per 750 board feet

TORQUE CONVERTERS:

Peak output shaft horsepower:

Normally 80% of input horsepower for a three-stage converter.

Output shaft speed at peak output horsepower:

Single-stage — 0.7 to 0.85 engine full load speed

Three-stage — 0.5 to 0.6 engine full load speed

Torque multiplication at or near stall:

Single-stage — 2.2 to 3.4 times engine torque

Three-stage — 3.6 to 5.4 times engine torque